Diagnostic statistical analyses to detect the seismicity and geodetic anomalies relative to the normal predictions

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and

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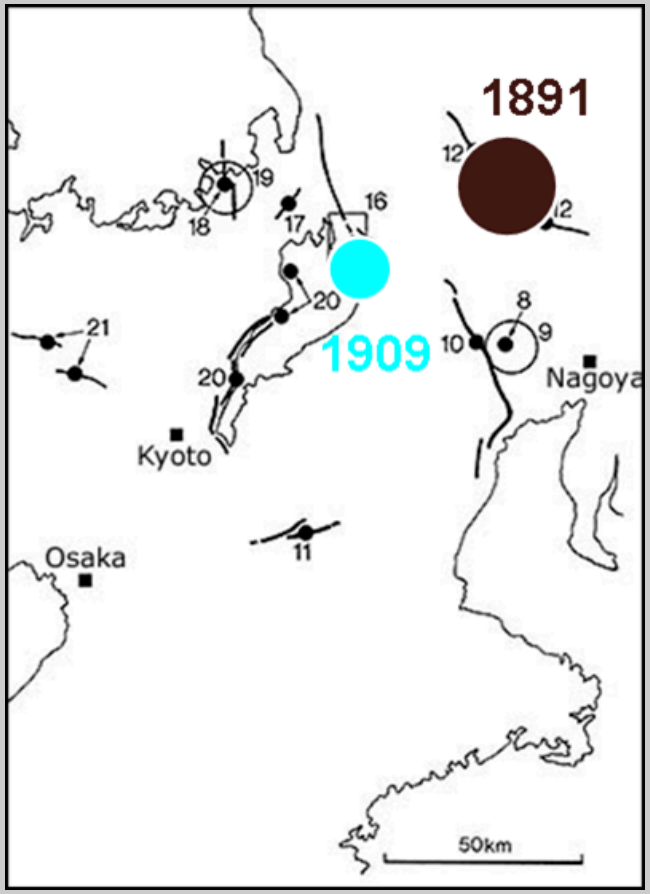
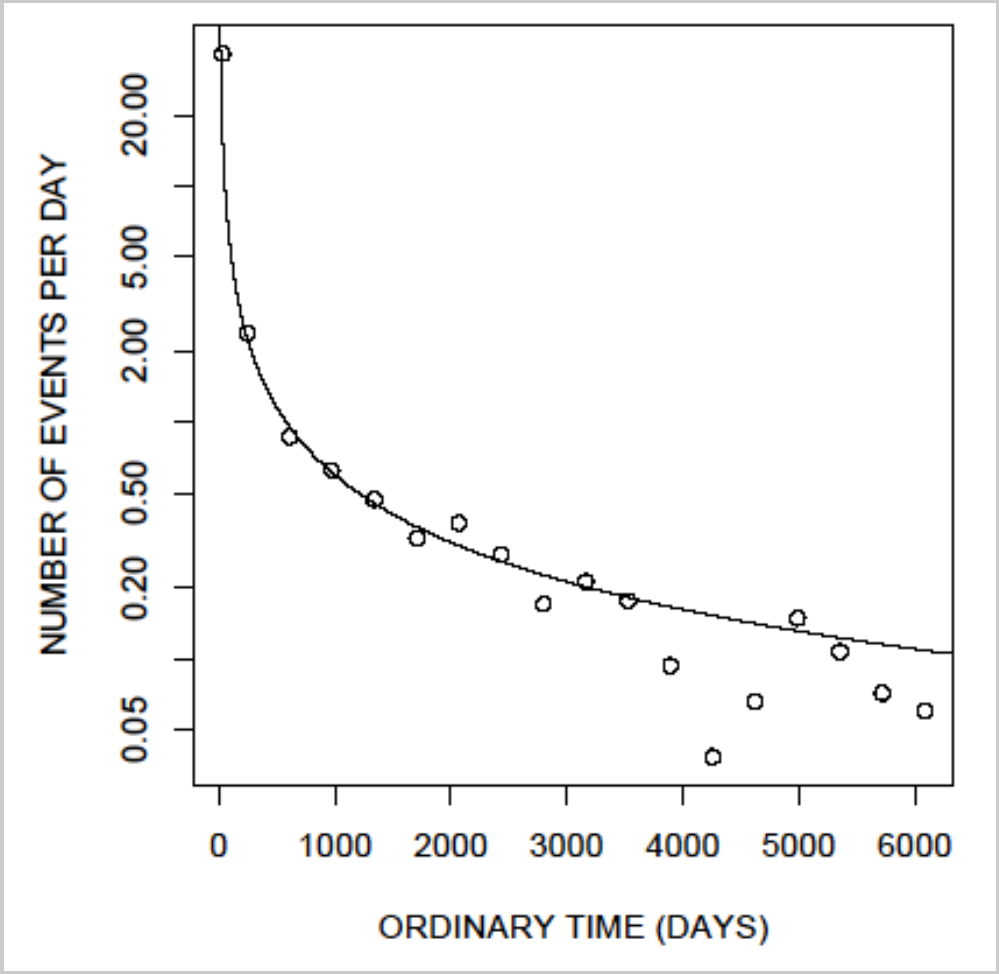
Aftershocks

Omori (1894)

$$n(t) = K(t+c)^{-1}$$

1891 Nobi Earthquake of M8.1





Utsu (1961)

The Omori-Utsu formula
for aftershock decay rate

$$v(t) = K(t + c)^{-p}$$

t : Elapsed time from the mainshock

K, c, p : constant parameters

Utsu (1961, 1969)

1891 Nobi (M8) Aftershock freq.

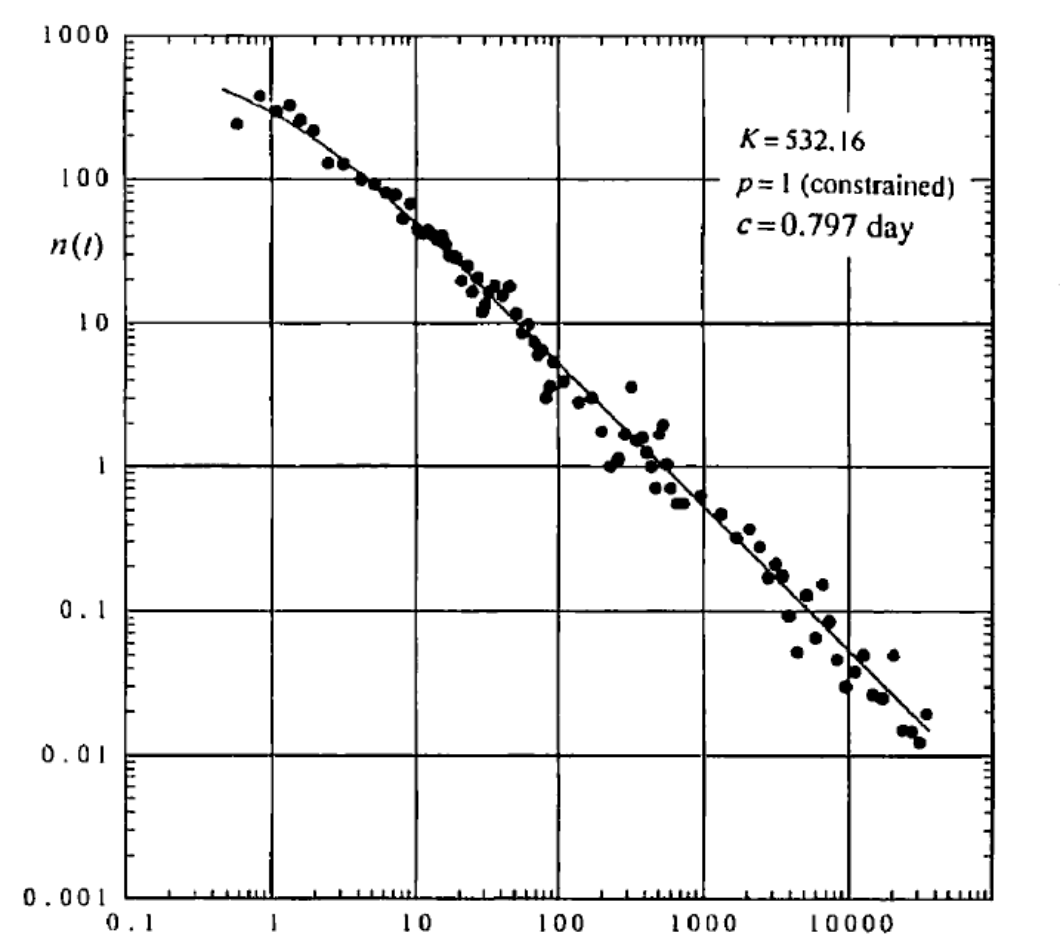


Fig. 1. Occurrence rate (top) and cumulative number (bottom) of felt earthquakes at Gifu after the Nobi earthquake of 1891. Smooth curves represent the Omori formula fitted to the data.

Data from Omori (1895) and Utsu (1969)

Ogata (1983, *J. Phys. Earth*)

Observed time interval: $[S, T]$

Occurrence time data; $t_1, t_2, \cdots, t_n$

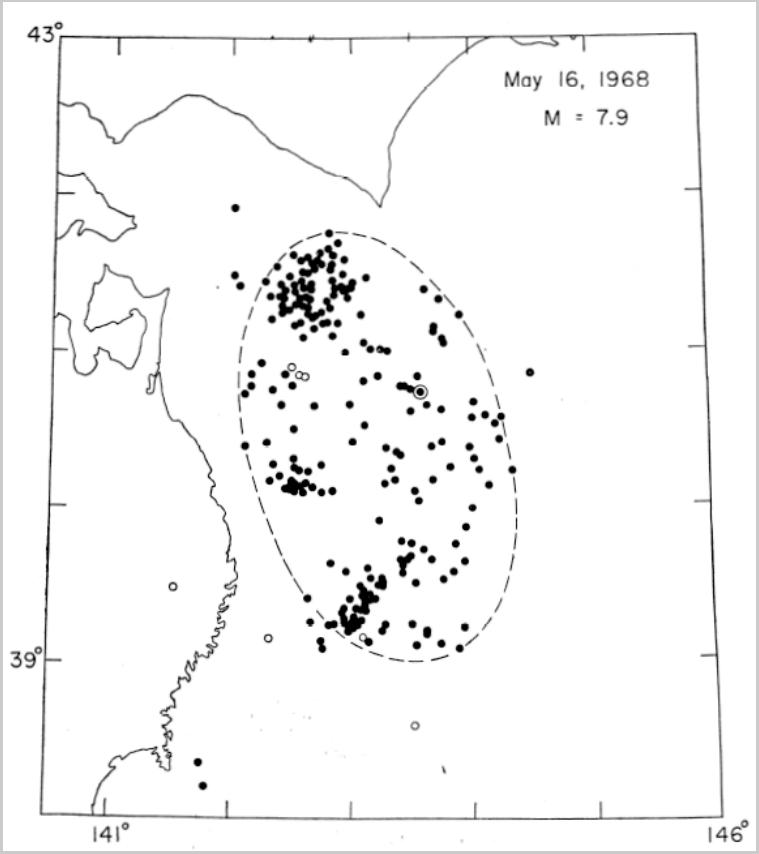
Log-likelihood function:

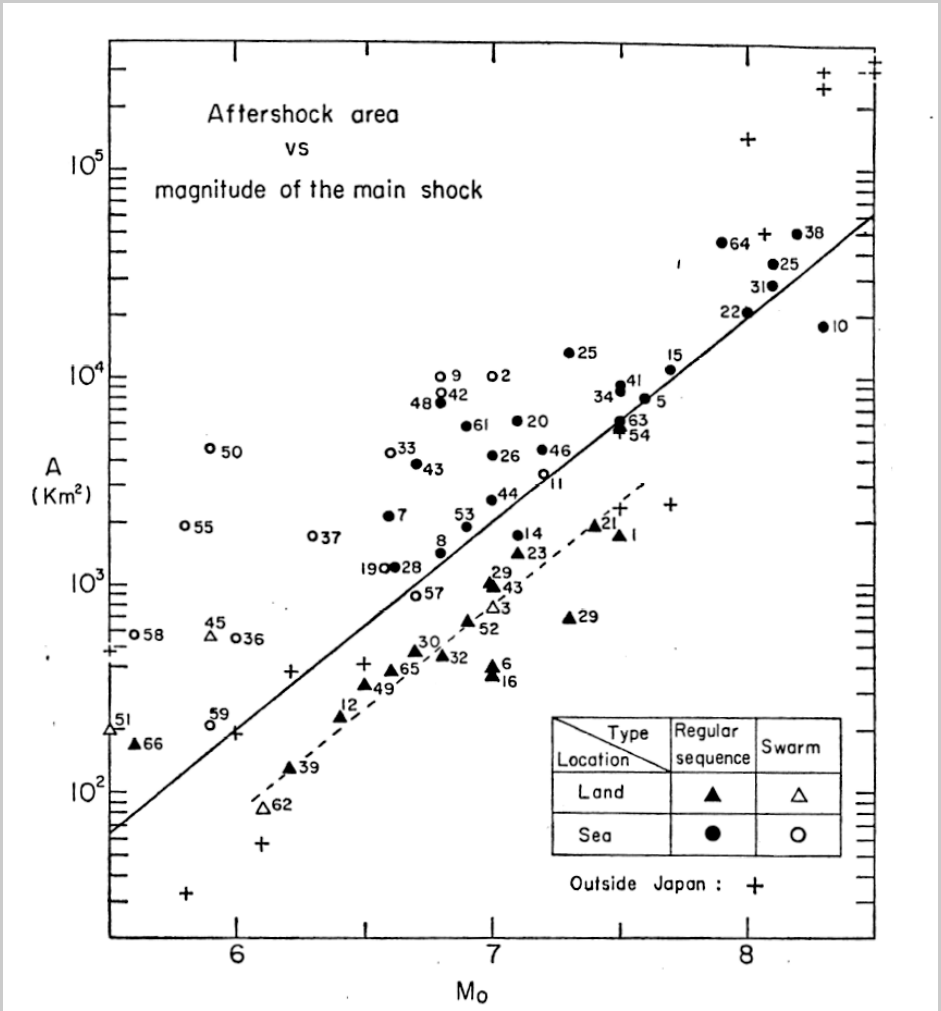
$$\ln L(\theta; S, T) = \sum_{S<t_i<T} \ln \lambda_\theta(t_i) - \int_S^T \lambda_\theta(t) dt$$

$$l(K, c, p) = \sum_{S<t_i<T} \ln \frac{K}{(t_i + c)^p} - \int_S^T \frac{K}{(t + c)^p} dt$$

Maximum Likelihood Estimate (**MLE**)

Utsu & Seki (1954)
Utsu (1969)





$$\log S = 1.02M - 4.01$$

$$\log L = 0.5M - 1.8$$

Utsu (1970, *Geophys. Bull. Hokkaido Univ.*)

Standard aftershock activity:

Occurrence rate of aftershock of M_s is

$$n(t) = \frac{10^{0.85(M_0 - M_s) - 1.83}}{(t + 0.3)^{1.3}}$$

during $1 < t < 100$ days ($M_0 >= 5.5$), where

***p*=1.3, *c*=0.3 and *b*=0.85 are median estimates.**

The constant 1.83 is the best fit to 66 aftershock sequences in Japan during 1926-1968

Utsu (1970) Secondary Aftershocks

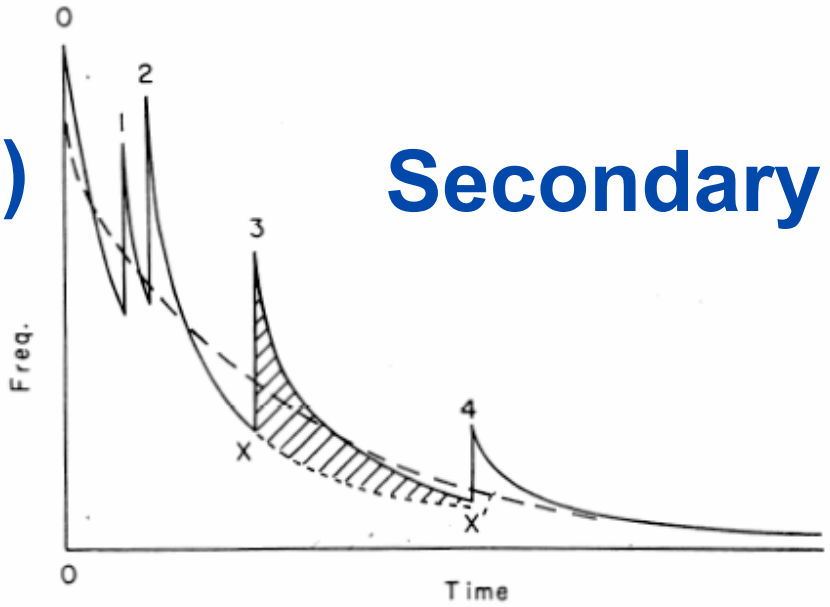
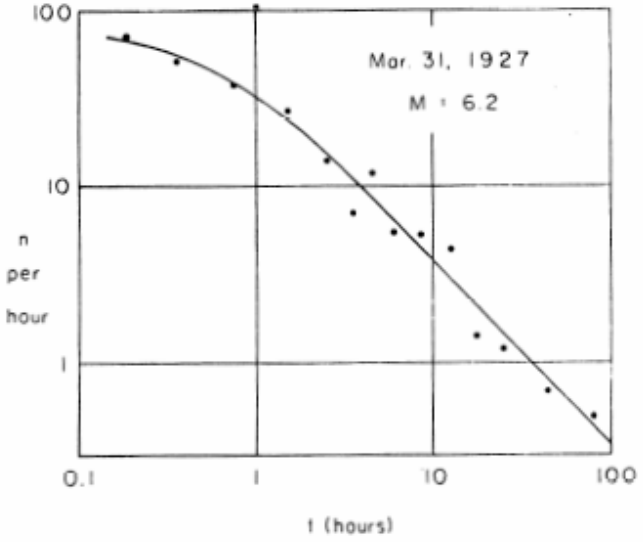
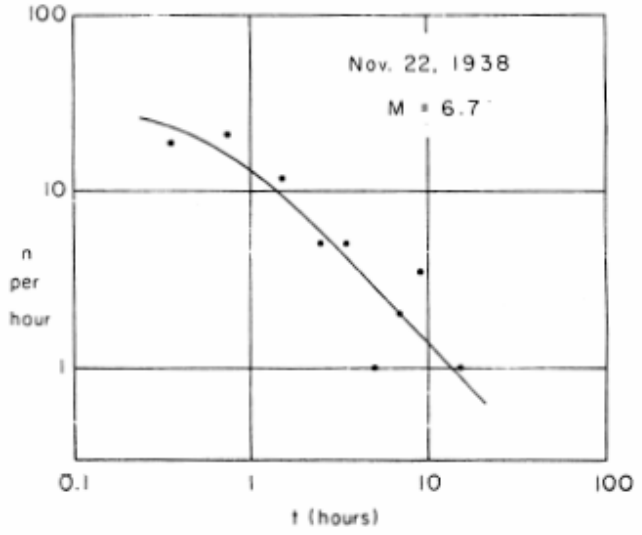


Fig. 105. A schematic graph of Type 1-C aftershock sequence. The borken line represents the curve for the modified Omori formula fitting the whole sequence. The shaded area indicate the secondary aftershocks triggered by shock 3.





Omori-Utsu formula:

$$\nu(t) = \frac{K}{(t+c)^p}$$

ETAS model:

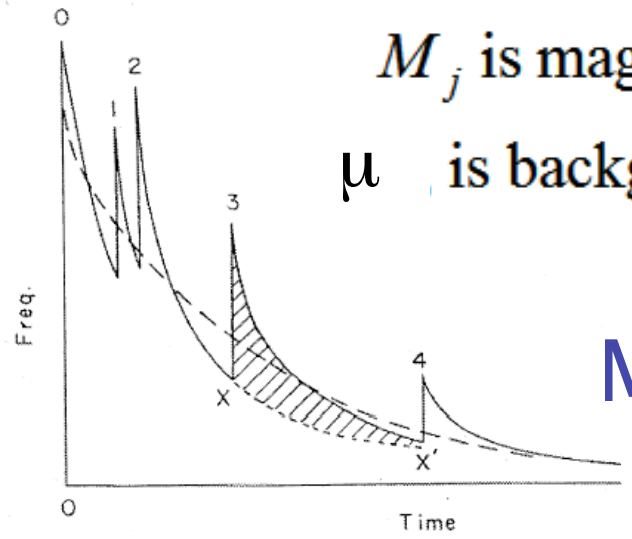
$$\lambda(t) = \mu + \sum_{\{j : t_j < t\}} e^{\alpha\{Mj - M_c\}} \nu(t - t_j)$$

where

t_j is occurrence time of jth event;

M_j is magnitude of jth event;

μ is background rate; and parameters are $(\lambda_0, K, c, \alpha, p)$.



Maximum Likelihood Estimates

Ogata

$$\lambda(t) = \mu + \sum_{t_i<t} c(m_i)g(t - t_i)$$

- Hawkes (1971, *J. Roy. Stats. Soc.* B) Self-exciting process
- Hawkes and Oakes (1974, *JAP*) → Epidemic-type model →
- Kendall (1949, *JRSS*B) Age-dependent birth & death branching process
- Hawkes & Adamopoulos (1973, *Bull. Int. Stats. Inst.*) Cluster earthquake cluster model
- Lomnitz (1974, *Global Tectonics and Earthquake Risk*, Elsevier) Tagged Klondike-type model
- Kagan & Knopoff (1981, *JGR*) Stochastic earthq. synthesis
- Ogata (1981, *IEEE-IT*) Thinning simulation algorithm
- Ogata and Akaike (1982, *JRSSB*, *AISM*) Maximum Likelihood Estimation

Space-Time ETAS model (Ogata,1998,AISM)

$$\lambda(t,x,y) = \mu + \sum_{\{j:\, t_j<t\}} \frac{K}{(t-t_j+c)^p} \left\{ \frac{Q_j(x,\ y)}{e^{\alpha M_j}} + d \right\}^{-q}$$

where

$$Q_j(x,\ y) = (x-x_j,\ y-y_j)\ S_j \begin{pmatrix} x-x_j \\ y-y_j \end{pmatrix}$$

Heterogeneity in Space

$$\mu \Longrightarrow \mu\,(x,y);$$

$$K \Longrightarrow K\,(x_j,y_j);\quad \alpha \Longrightarrow \alpha\,(x_j,y_j);$$

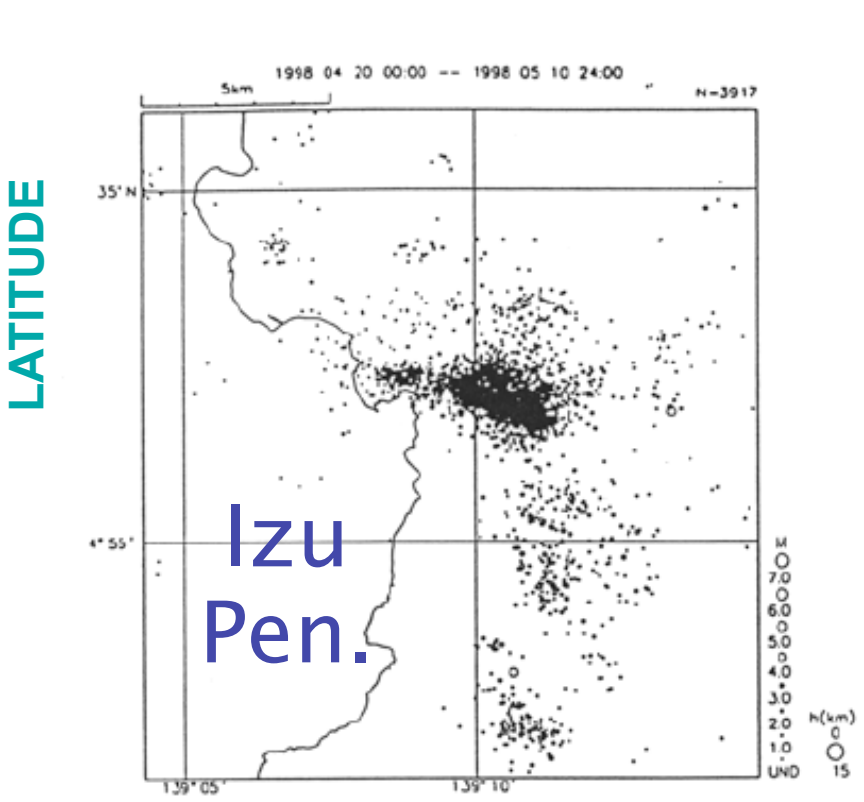
$$p \Longrightarrow p\,(x_j,y_j);\quad q \Longrightarrow q\,(x_j,y_j)$$

Hierarchical Space-Time (HIST) ETAS model

estimated an Objective Bayesian method with smoothness constraints

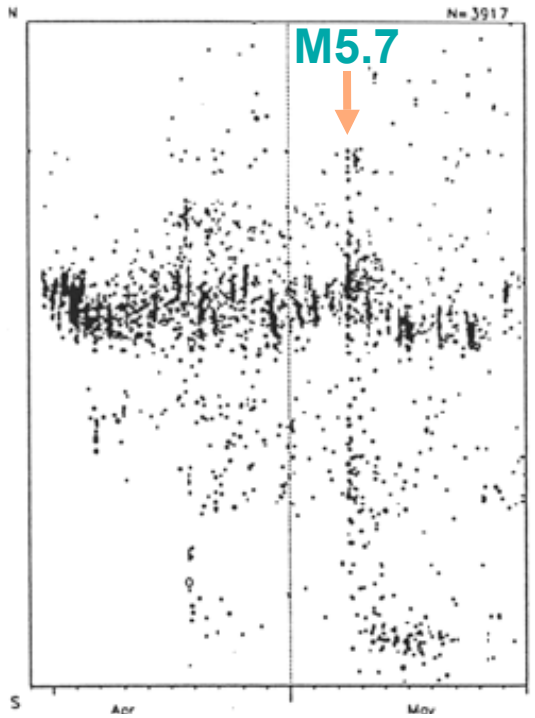
Ogata(2003,JGR)

Off the East coast of Izu Peninsula Swarm



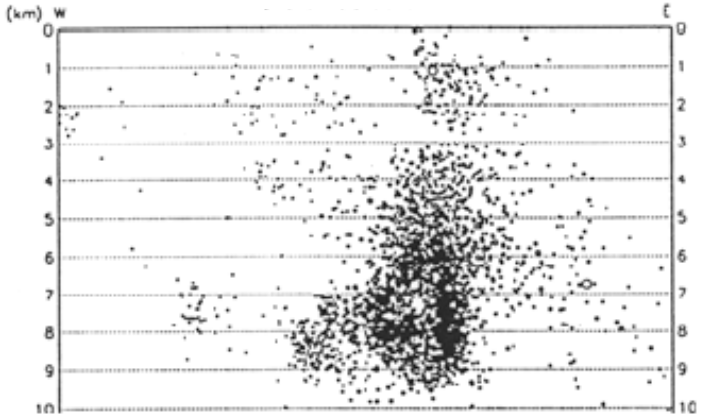
LATITUDE

TIME



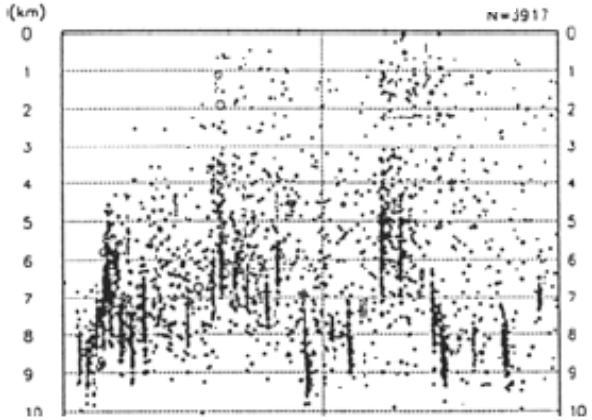
LATITUDE

LONGITUDE



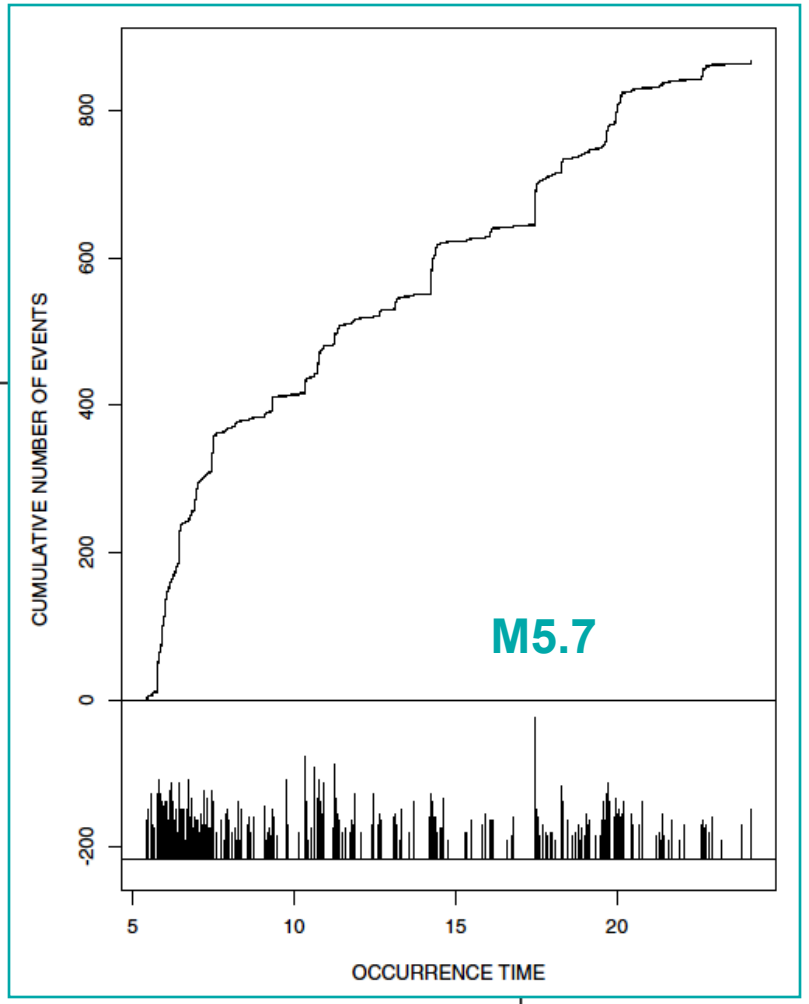
DEPTH

TIME



DEPTH

Off the East coast of Izu Peninsula Swarm



$$\lambda(t|H_t) = \mu(t) + \sum_{\{j:\ t_j<t\}} \frac{K_0 e^{\alpha(M_j - M_c)}}{(t - t_j + c)^p}$$

μ (t)

M5.7

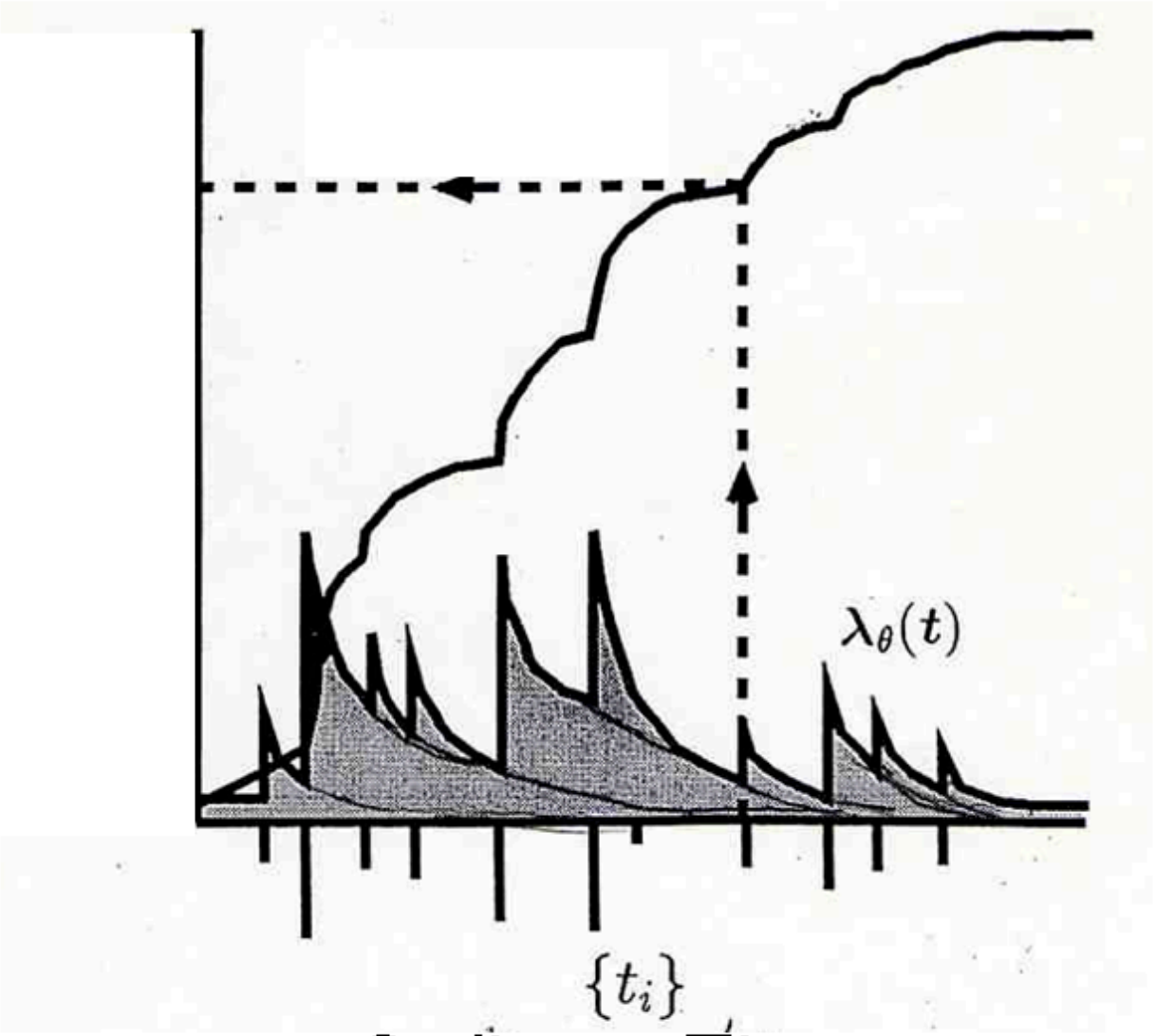
Exogeneous occurrence rate / day

Elapsed days from 16 APR 1998

Diagnostic Analysis by Time Transformation

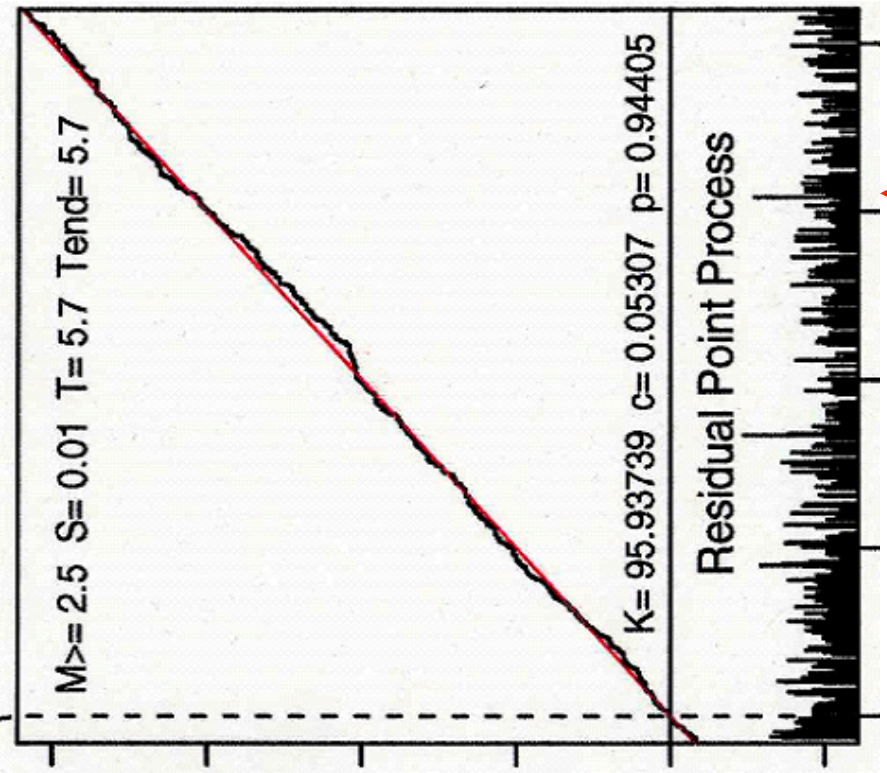
Theoretical cumulative number of the events:

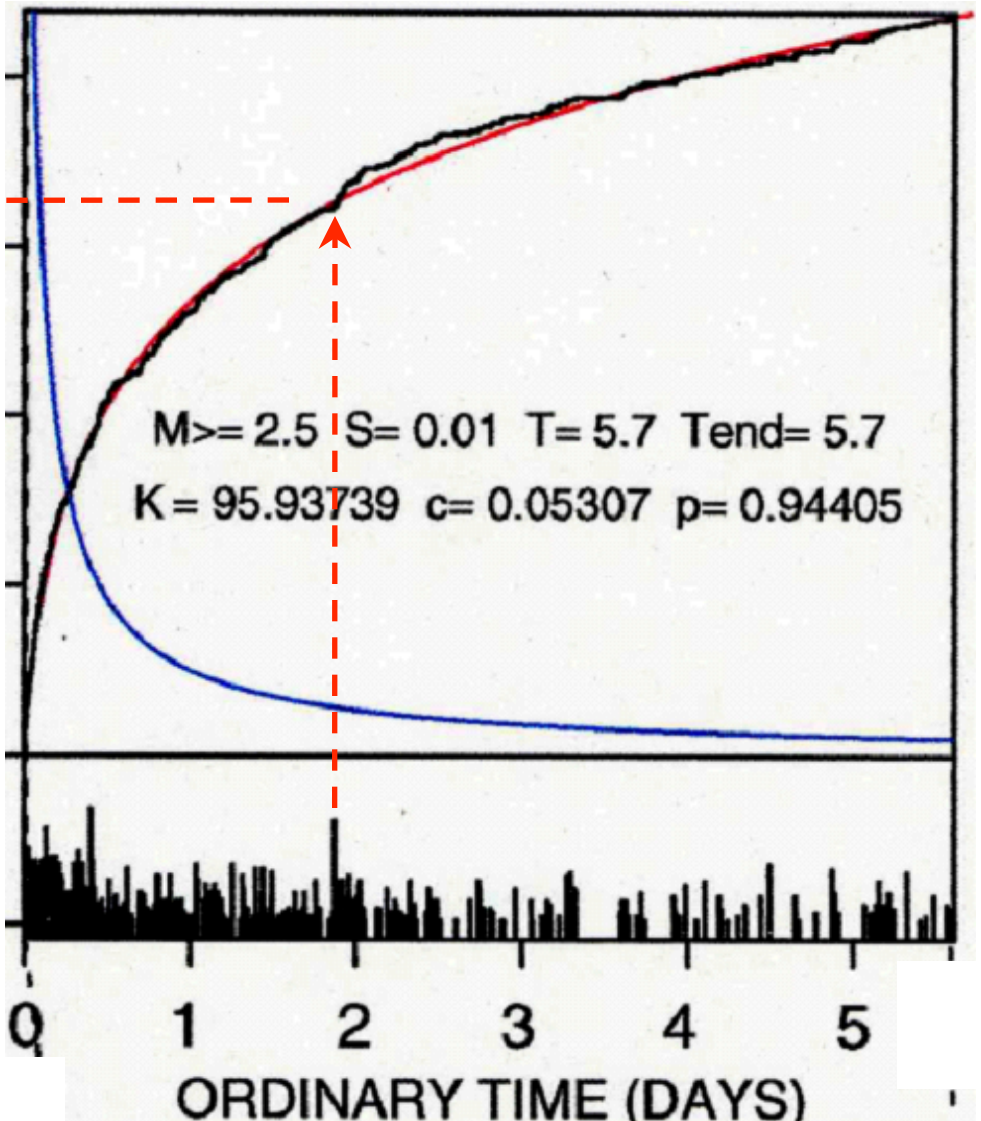
$$\Lambda(t) = \int_0^t \lambda(s)\, ds$$

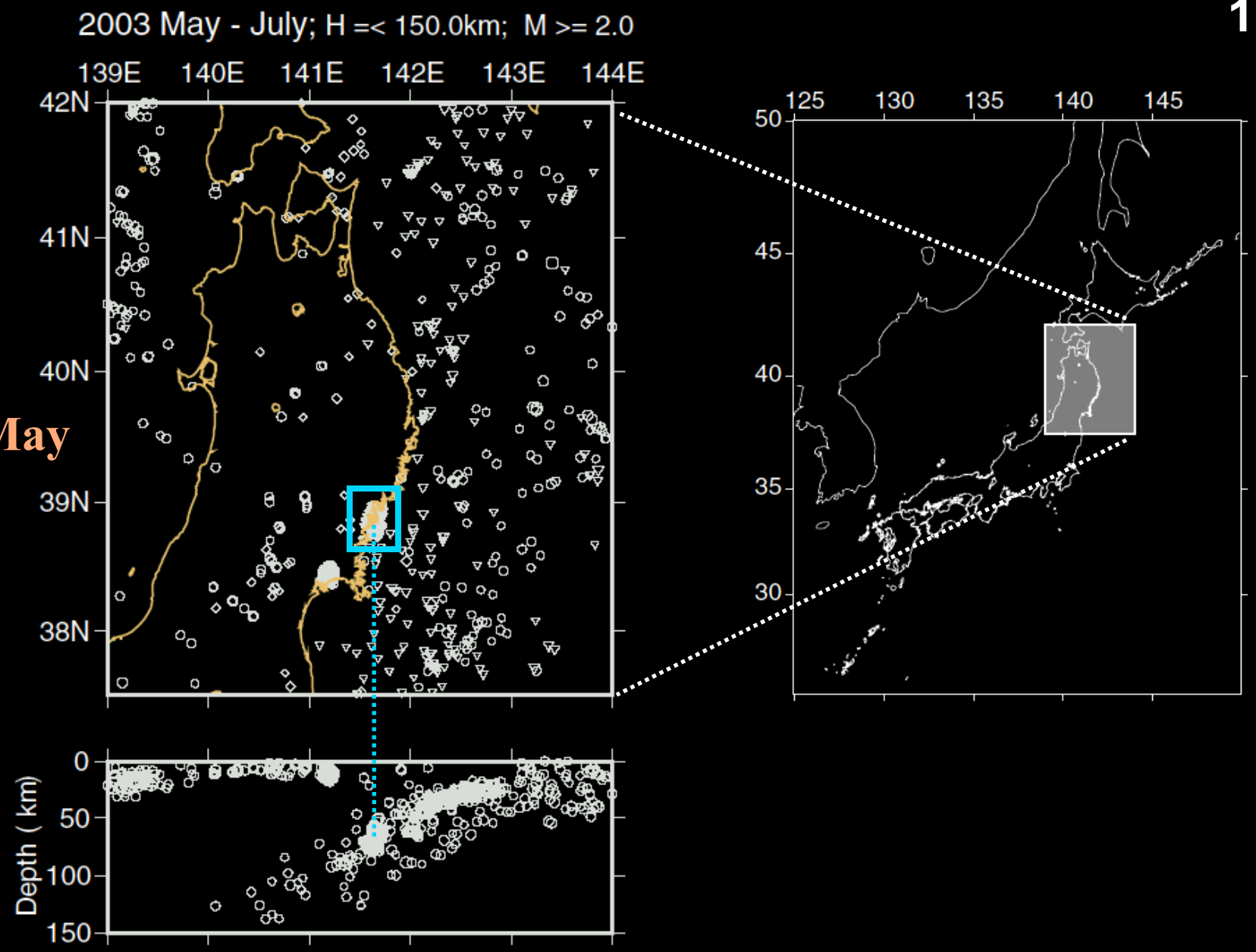


Theoretical cumulative number of the events:

$$\Lambda(t) = \int_0^t \lambda(s)\, ds$$





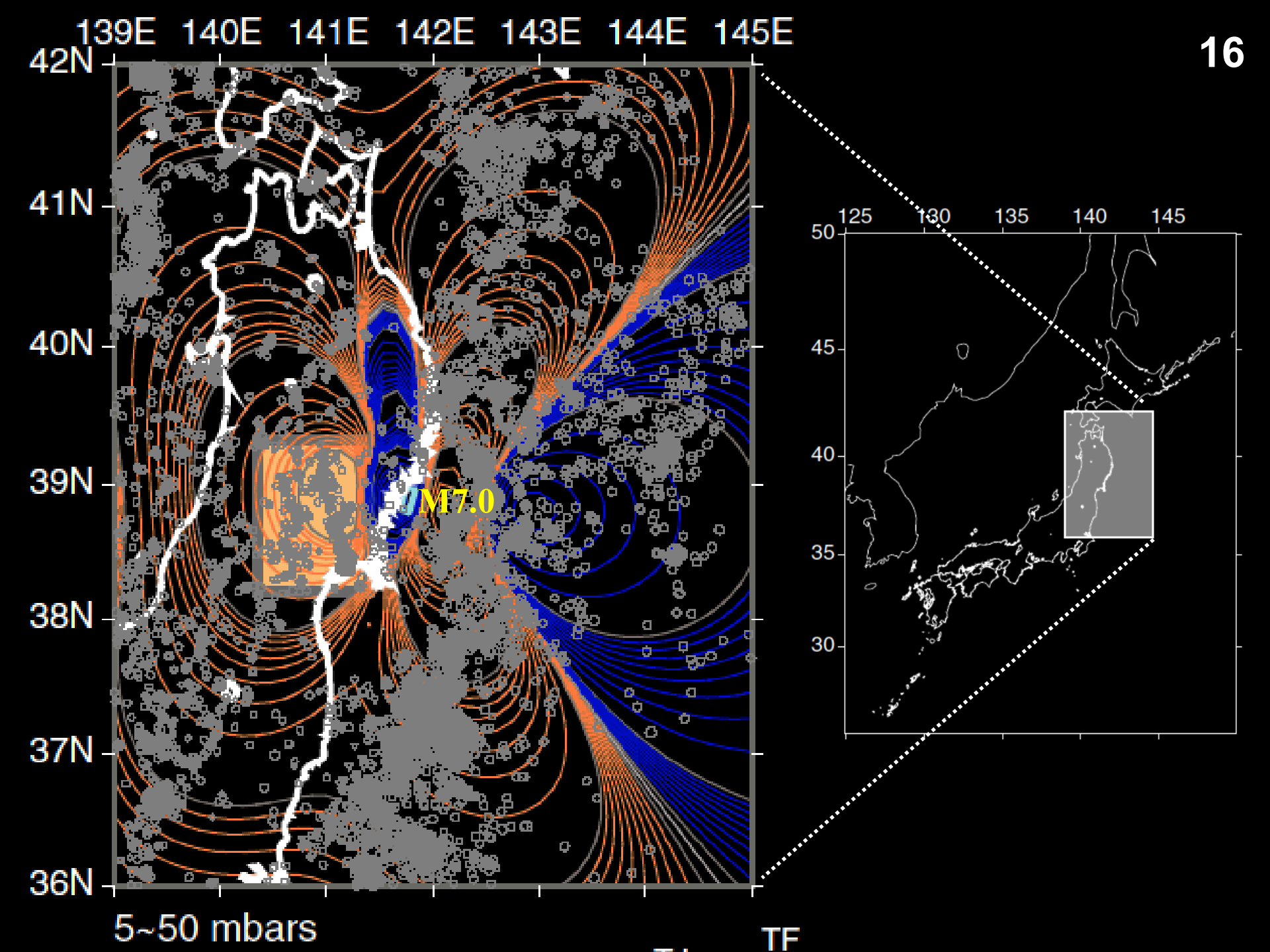


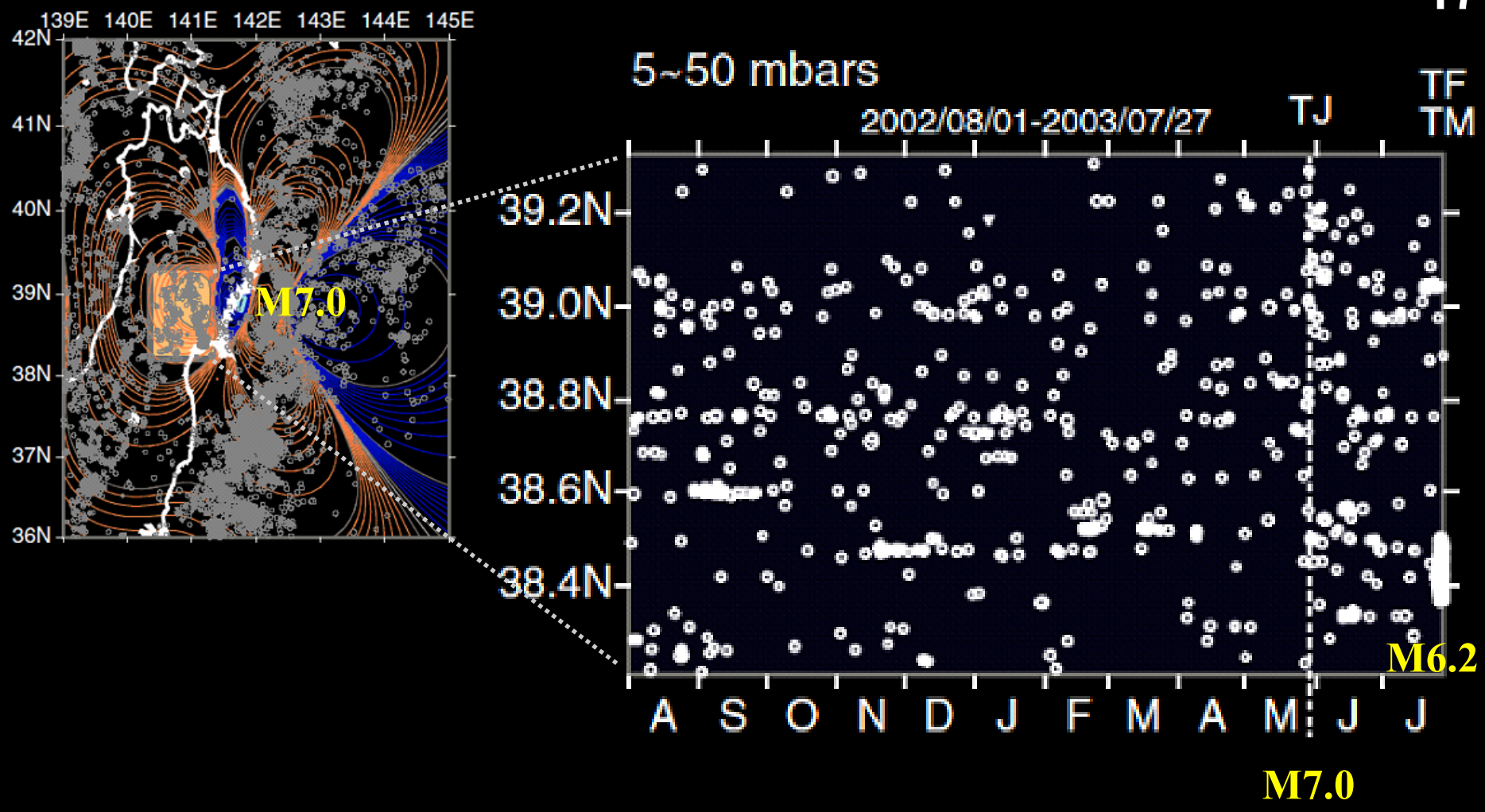
M7.0

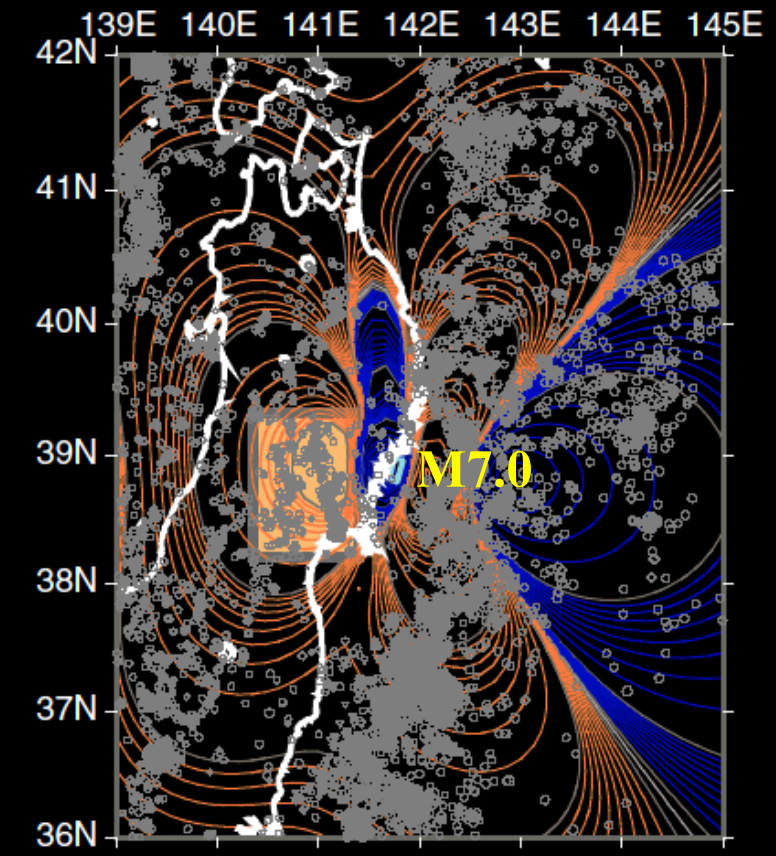
2003 May

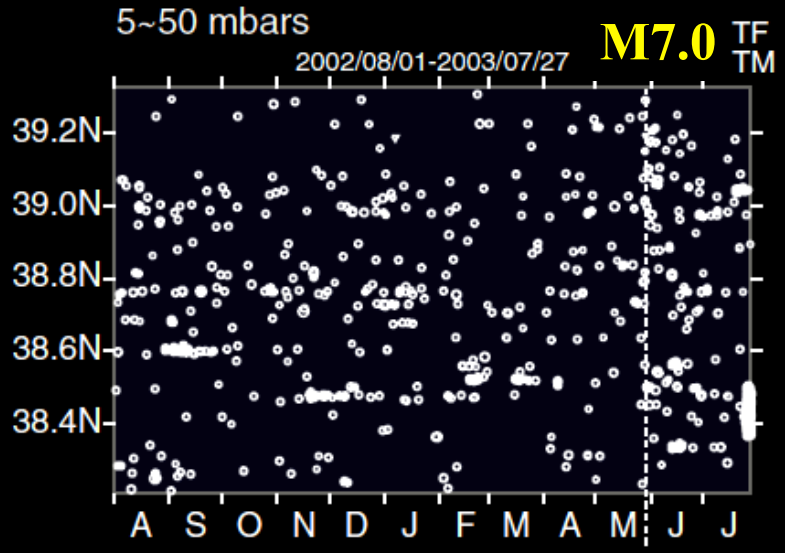
depth 71km

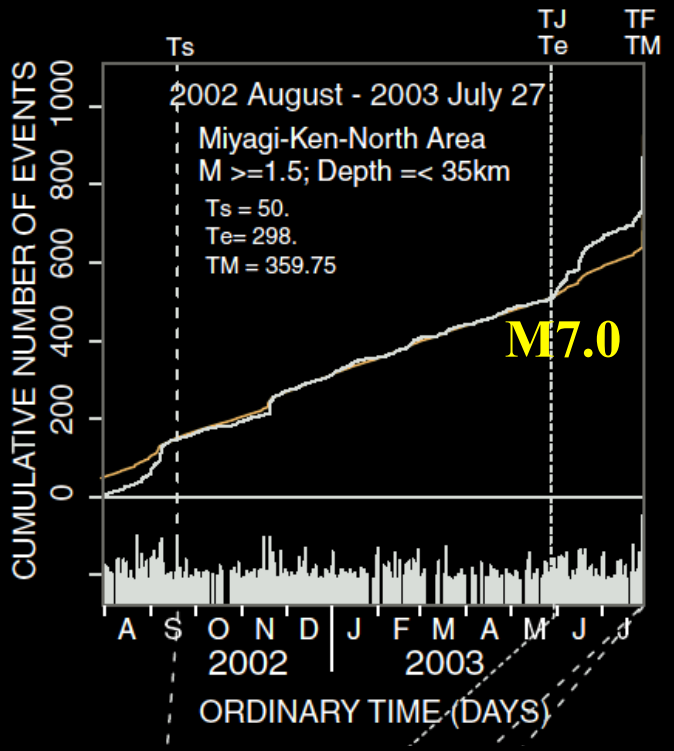
M6.2, 2003 July, depth 12km

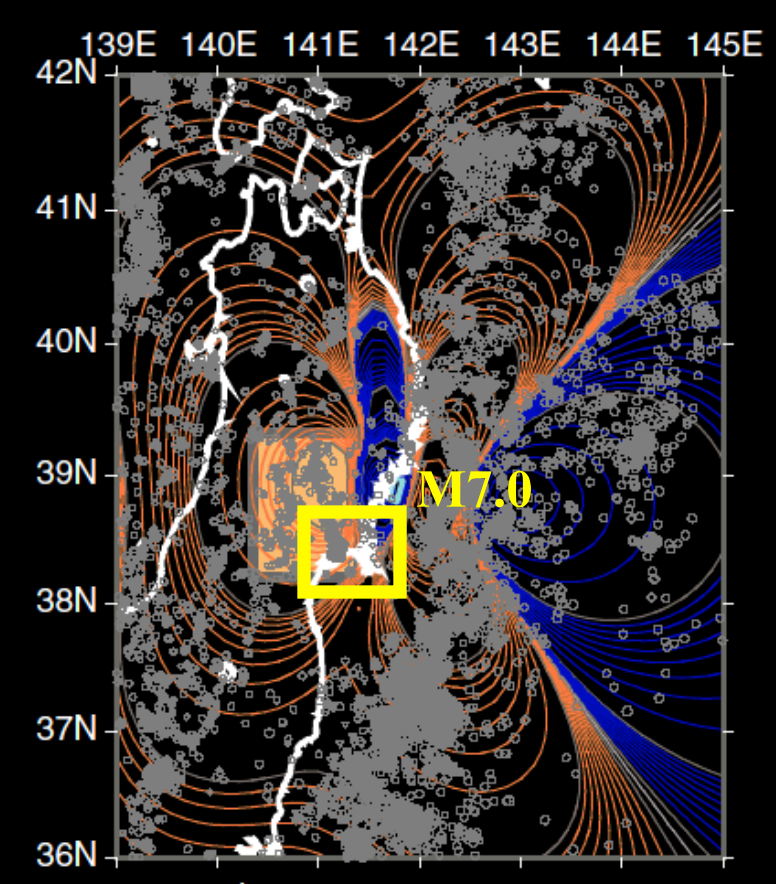

139E
140E
141E
142E
143E
144E
145E
42N
41N
40N
39N
38N
37N
36N
M7.0
125
130
135
140
145
50
45
40
35
30
5~50 mbars
TF

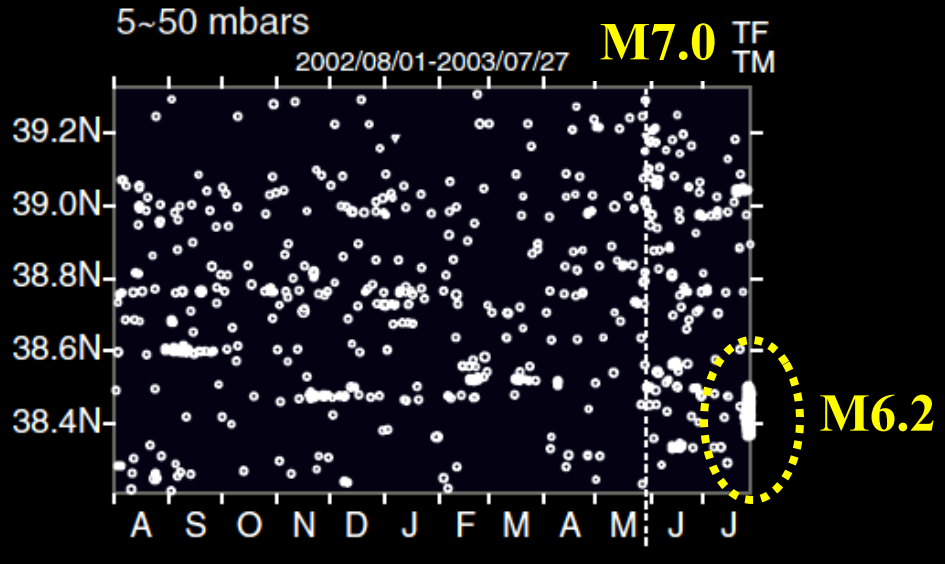

139E 140E 141E 142E 143E 144E 145E
42N
41N
40N
39N
38N
37N
36N
M7.0
5~50 mbars
2002/08/01-2003/07/27
TJ
TF
TM
39.2N
39.0N
38.8N
38.6N
38.4N
M6.2
A S O N D J F M A M J J
M7.0

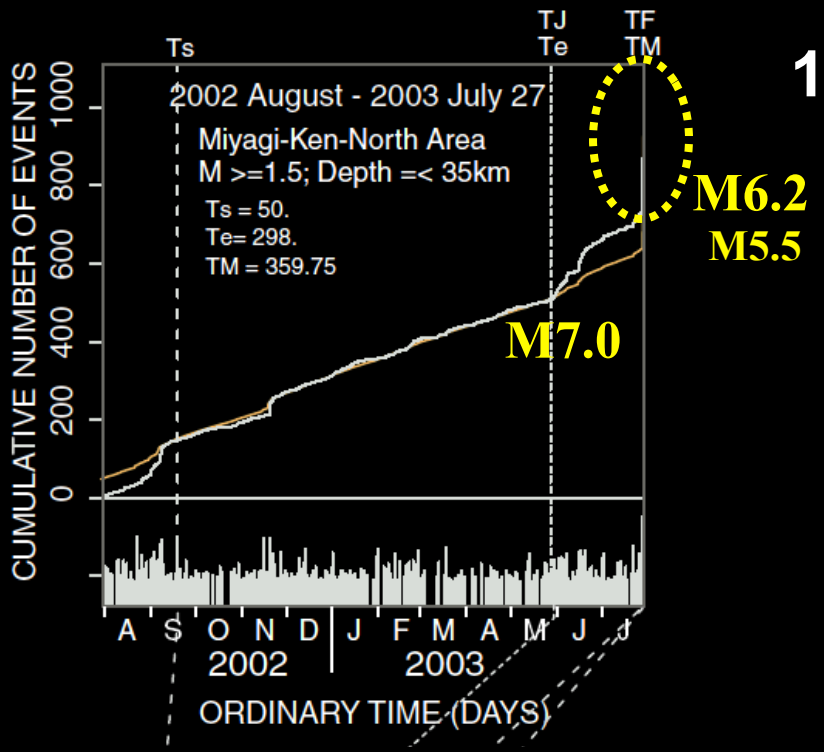

139E 140E 141E 142E 143E 144E 145E
42N
41N
40N
39N
38N
37N
36N
M7.0

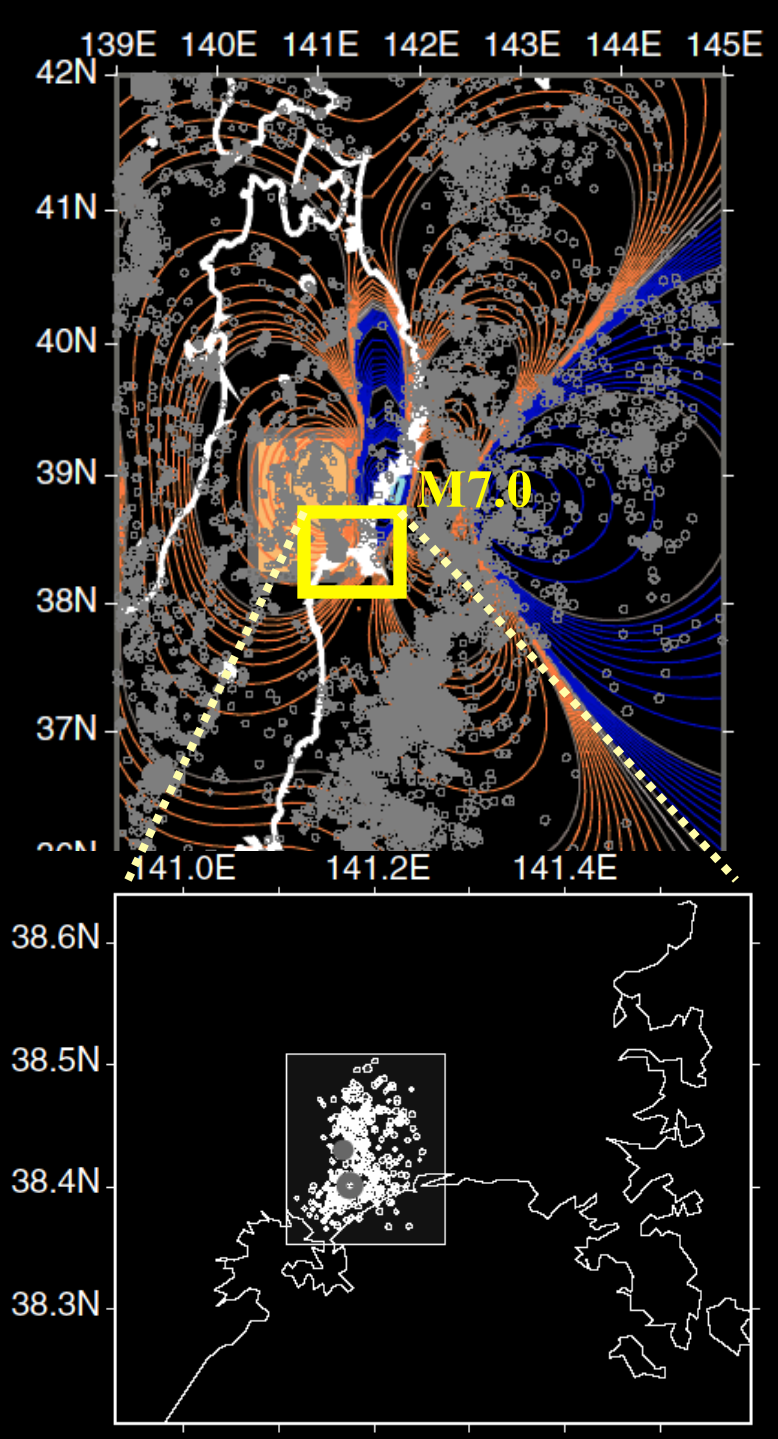

5~50 mbars
2002/08/01-2003/07/27
M7.0
TF
TM
39.2N
39.0N
38.8N
38.6N
38.4N
A S O N D J F M A M J J
M6.2

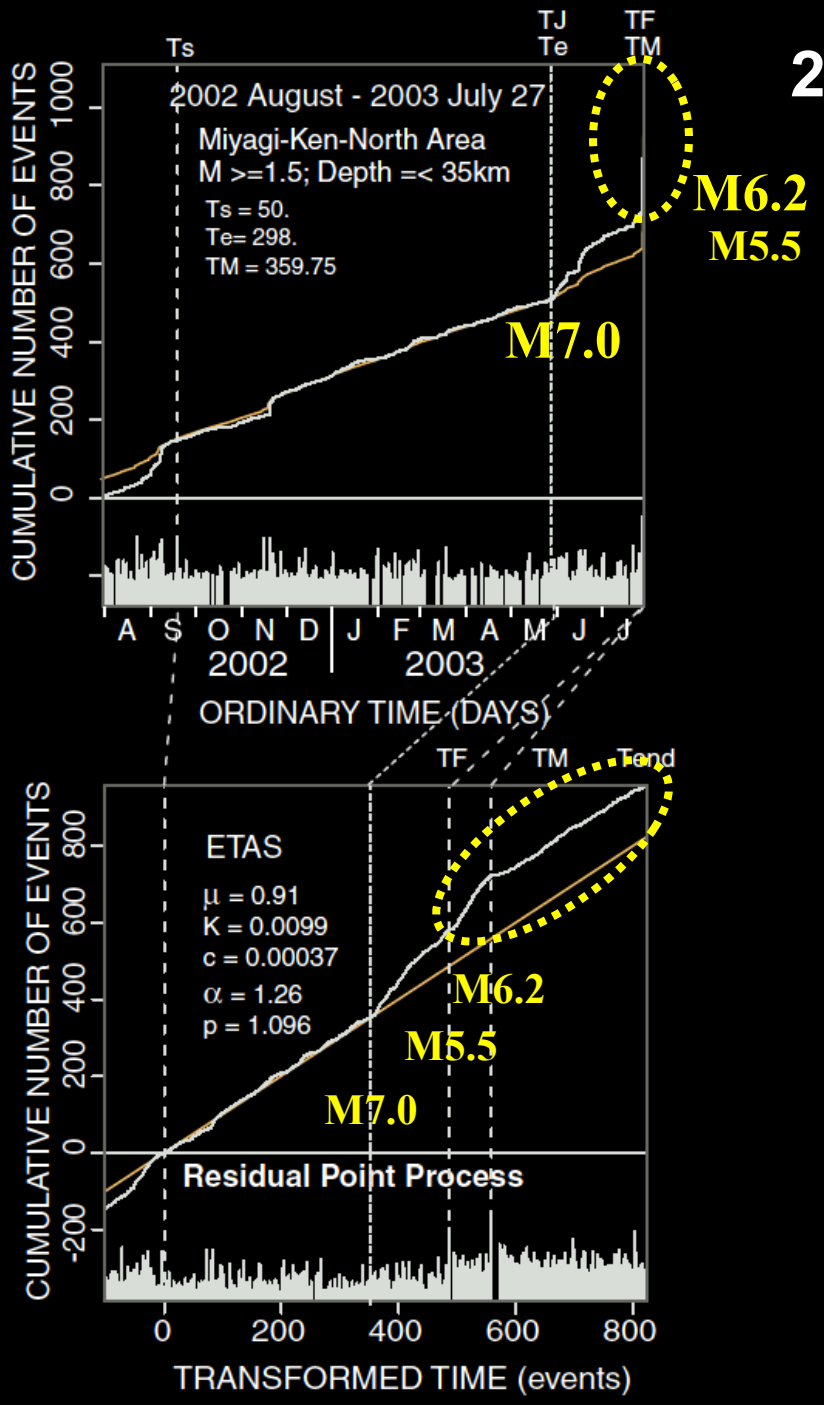

Ts
TJ
Te
TF
TM
2002 August - 2003 July 27
Miyagi-Ken-North Area
M >=1.5; Depth =< 35km
Ts = 50.
Te= 298.
TM = 359.75
CUMULATIVE NUMBER OF EVENTS
0 200 400 600 800 1000
M7.0
M6.2
A S O N D J F M A M J J
2002
2003
ORDINARY TIME (DAYS)


139E 140E 141E 142E 143E 144E 145E
42N
41N
40N
39N
38N
37N
36N
M7.0

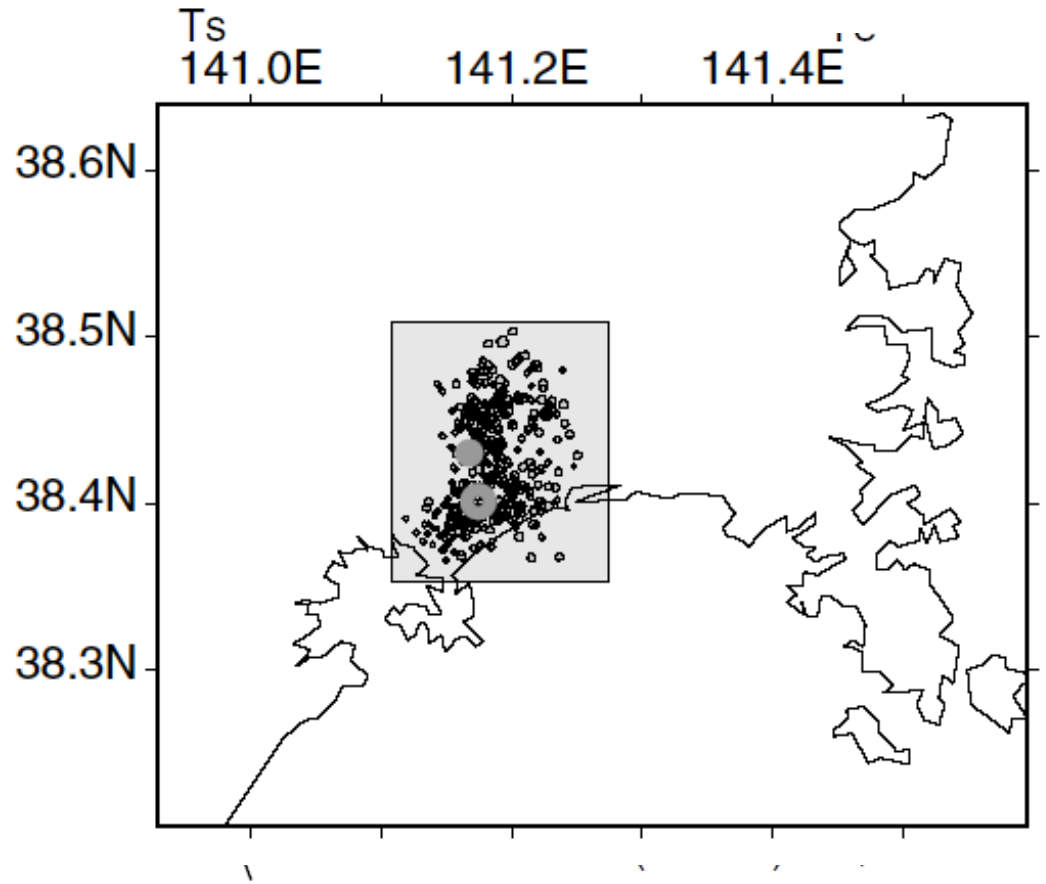

5~50 mbars
2002/08/01-2003/07/27
M7.0
TF
TM
39.2N
39.0N
38.8N
38.6N
38.4N
A S O N D J F M A M J J
M6.2


Ts
TJ
Te
TF
TM
2002 August - 2003 July 27
Miyagi-Ken-North Area
M >=1.5; Depth =< 35km
Ts = 50.
Te= 298.
TM = 359.75
CUMULATIVE NUMBER OF EVENTS
0 200 400 600 800 1000
M6.2
M5.5
M7.0
A S O N D J F M A M J J
2002
2003
ORDINARY TIME (DAYS)

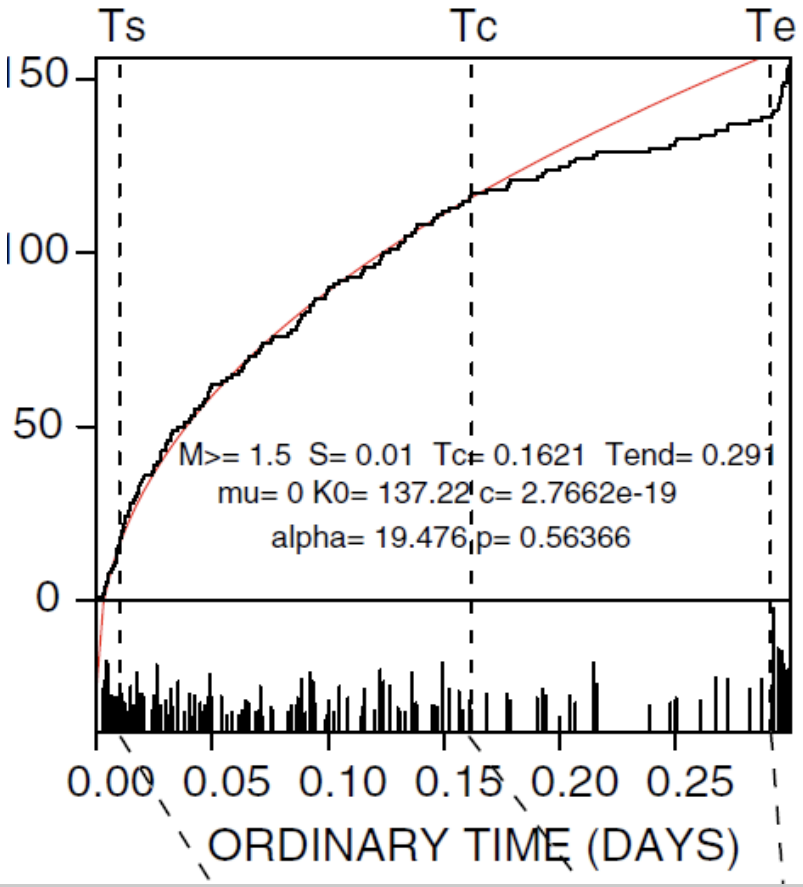

139E 140E 141E 142E 143E 144E 145E
42N
41N
40N
39N
38N
37N
M7.0
141.0E 141.2E 141.4E
38.6N
38.5N
38.4N
38.3N


Ts
TJ
Te
TF
TM
2002 August - 2003 July 27
Miyagi-Ken-North Area
M >=1.5; Depth =< 35km
Ts = 50.
Te= 298.
TM = 359.75
M6.2
M5.5
M7.0
CUMULATIVE NUMBER OF EVENTS
0 200 400 600 800 1000
A S O N D J F M A M J J
2002
2003
ORDINARY TIME (DAYS)
TF
TM
Tend
ETAS
μ = 0.91
K = 0.0099
c = 0.00037
α = 1.26
p = 1.096
M6.2
M5.5
M7.0
Residual Point Process
-200 0 200 400 600 800
TRANSFORMED TIME (events)

2003 Miyagi-Ken-North foreshocks (M >=1.5) till the mainshock

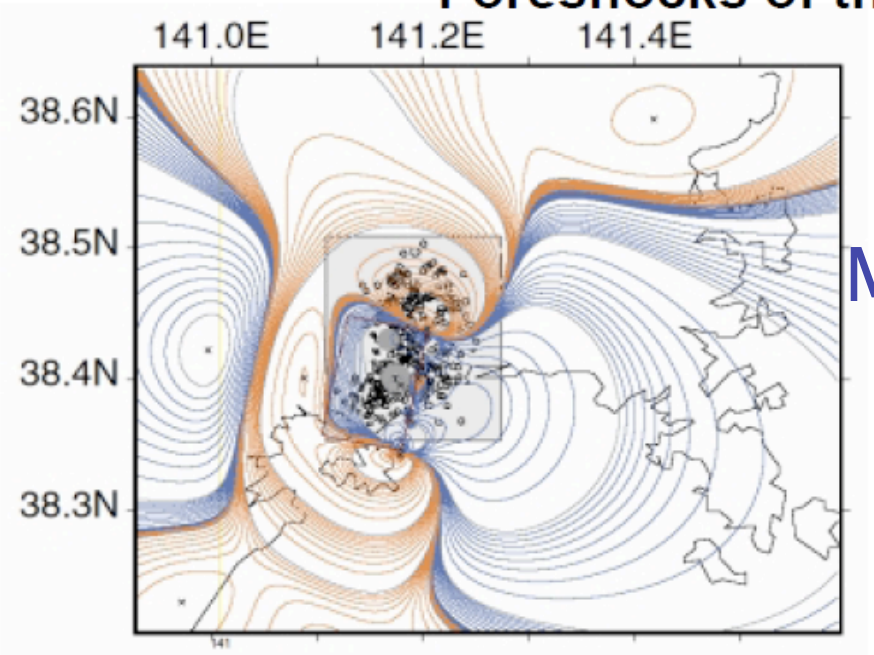


A change-point

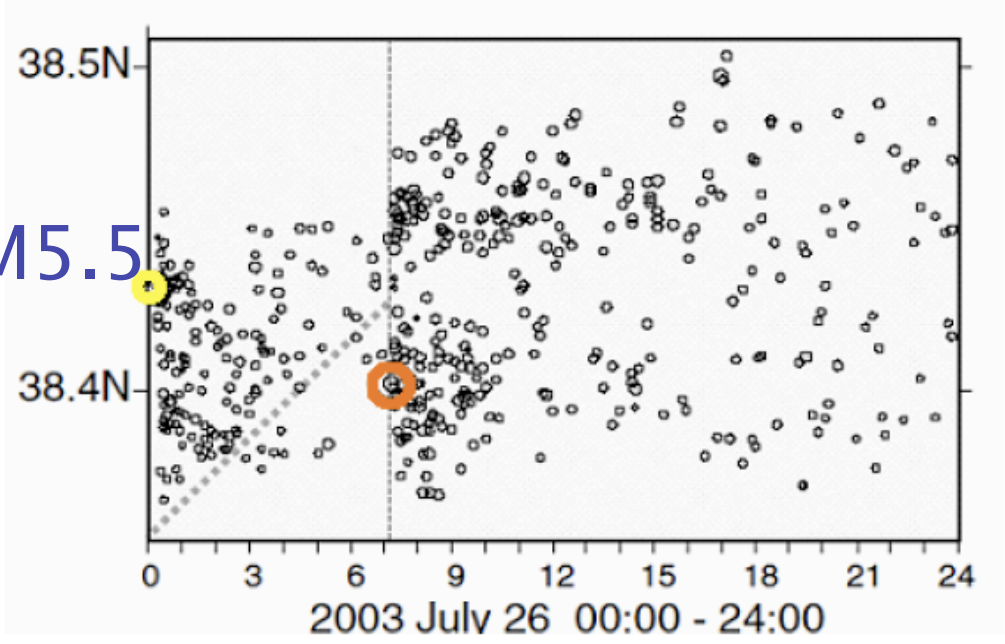


M6.2

2003年M6.2宮城県北部地震の前震
Foreshocks of the Miyagi-Ken-North



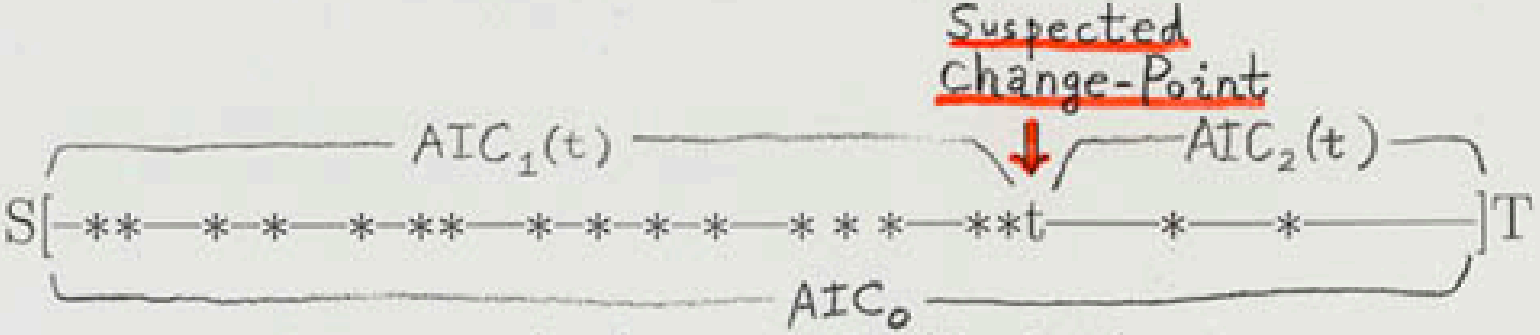
M5.5



Change-Point Analysis

Change-Point Analysis by the AIC

$$AIC = (-2)\max\{\text{log-likelihood}\} + 2\{\text{number of parameters}\}$$



$$AIC_0 = (-2)\max_{\theta} \log_e L(\theta;\ S, T) + 2k_0,$$

$$AIC_1(t) = (-2)\max_{\theta} \log_e L(\theta;\ S, t) + 2k_1,$$

$$AIC_2(t) = (-2)\max_{\theta} \log_e L(\theta;\ t, T) + 2k_2;$$

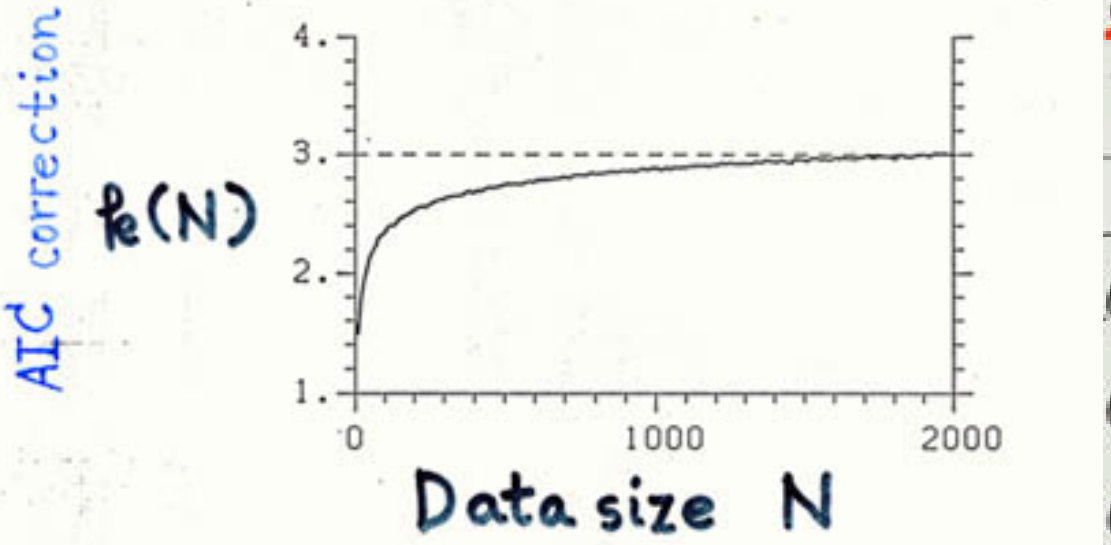
AIC_0 is compared with $AIC_{12}(t) + 2k(N)$ to choose the case of smaller value, where

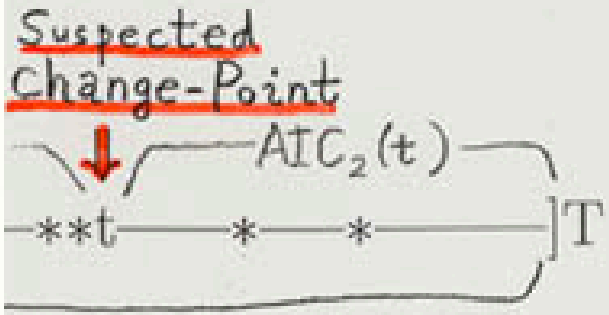
$$AIC_{12}(t) = AIC_1(t) + AIC_2(t),$$

and $k(N)$ is the bias correction in search of t minimizing $AIC_{12}(t)$ (*change-point problem*) and is a certain function of the number of events N in the interval $[S, T]$.

Change-Point Analysis by the AIC

$AIC_{12} = AIC_1 + AIC_2 + 2k(N)$ {number of parameters}





$\theta;\ S, T) + 2k_0,$

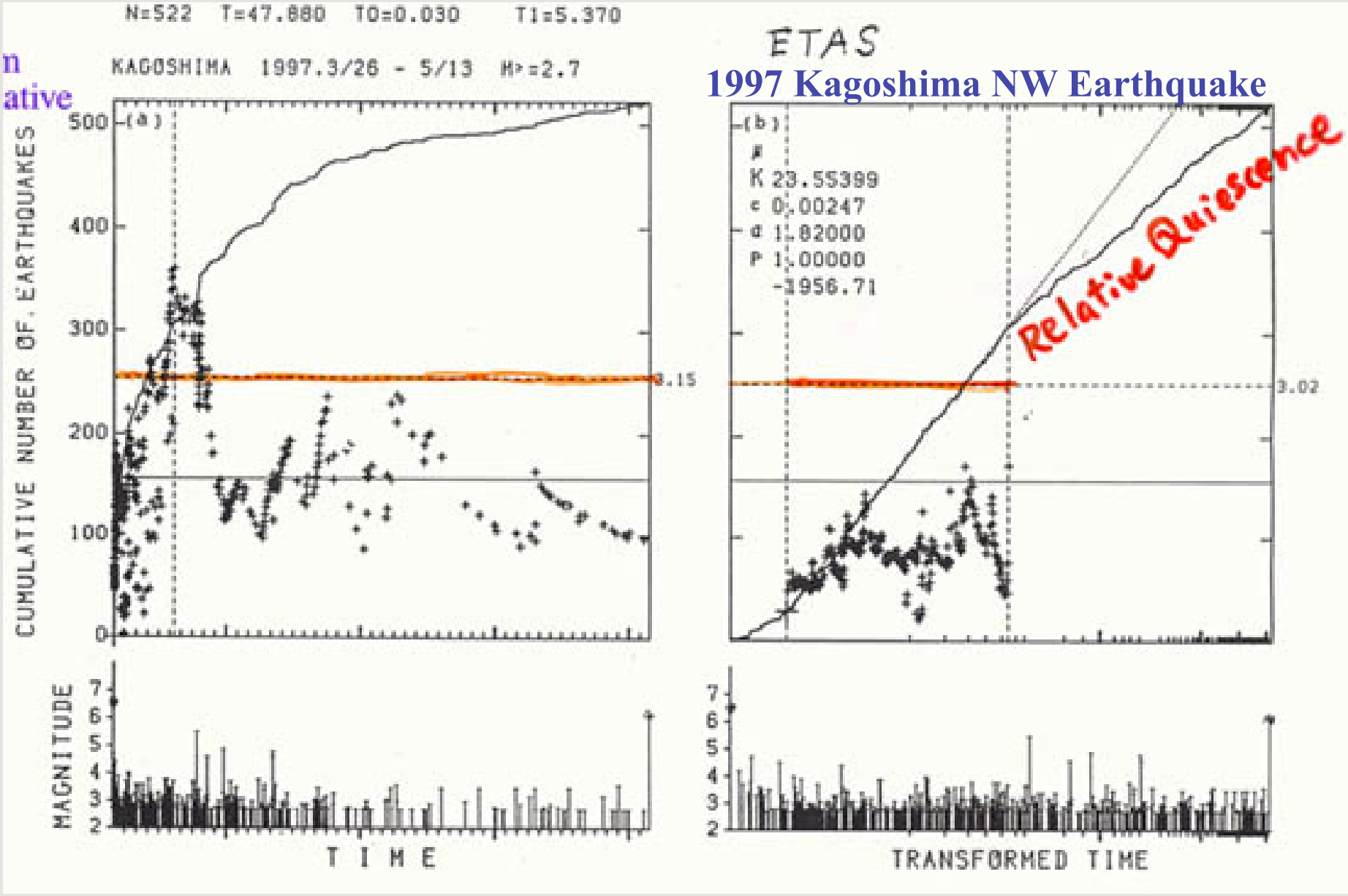
$\theta;\ S, t) + 2k_1,$

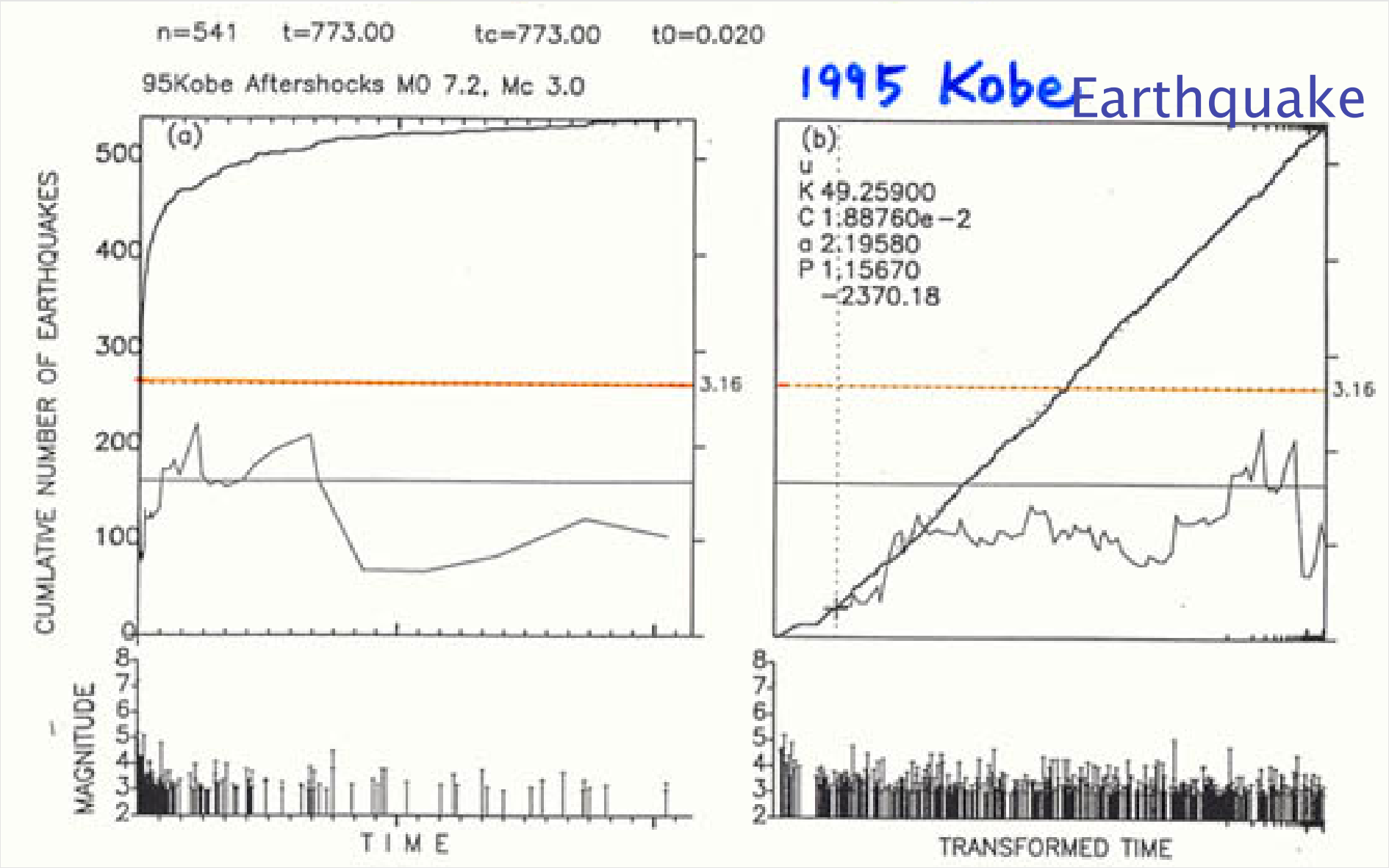
$\theta;\ t, T) + 2k_2;$

AIC_0 is compared with $AIC_{12}(t) + 2k(N)$ to choose the case of smaller value, where

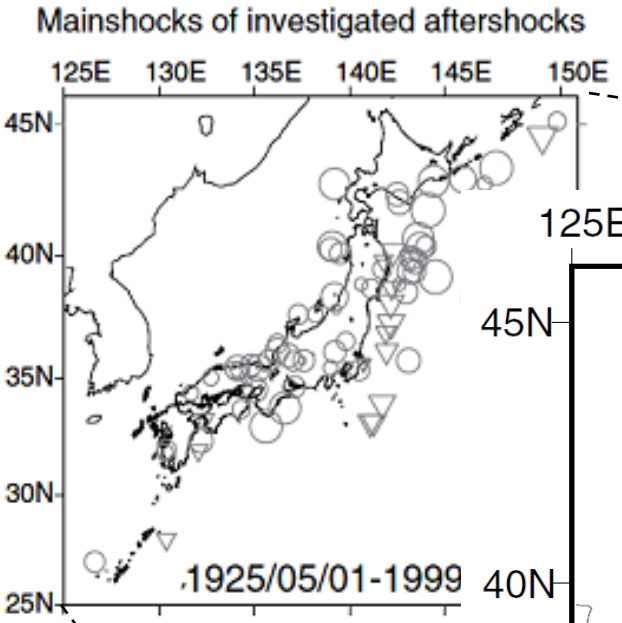
$$AIC_{12}(t) = AIC_1(t) + AIC_2(t),$$

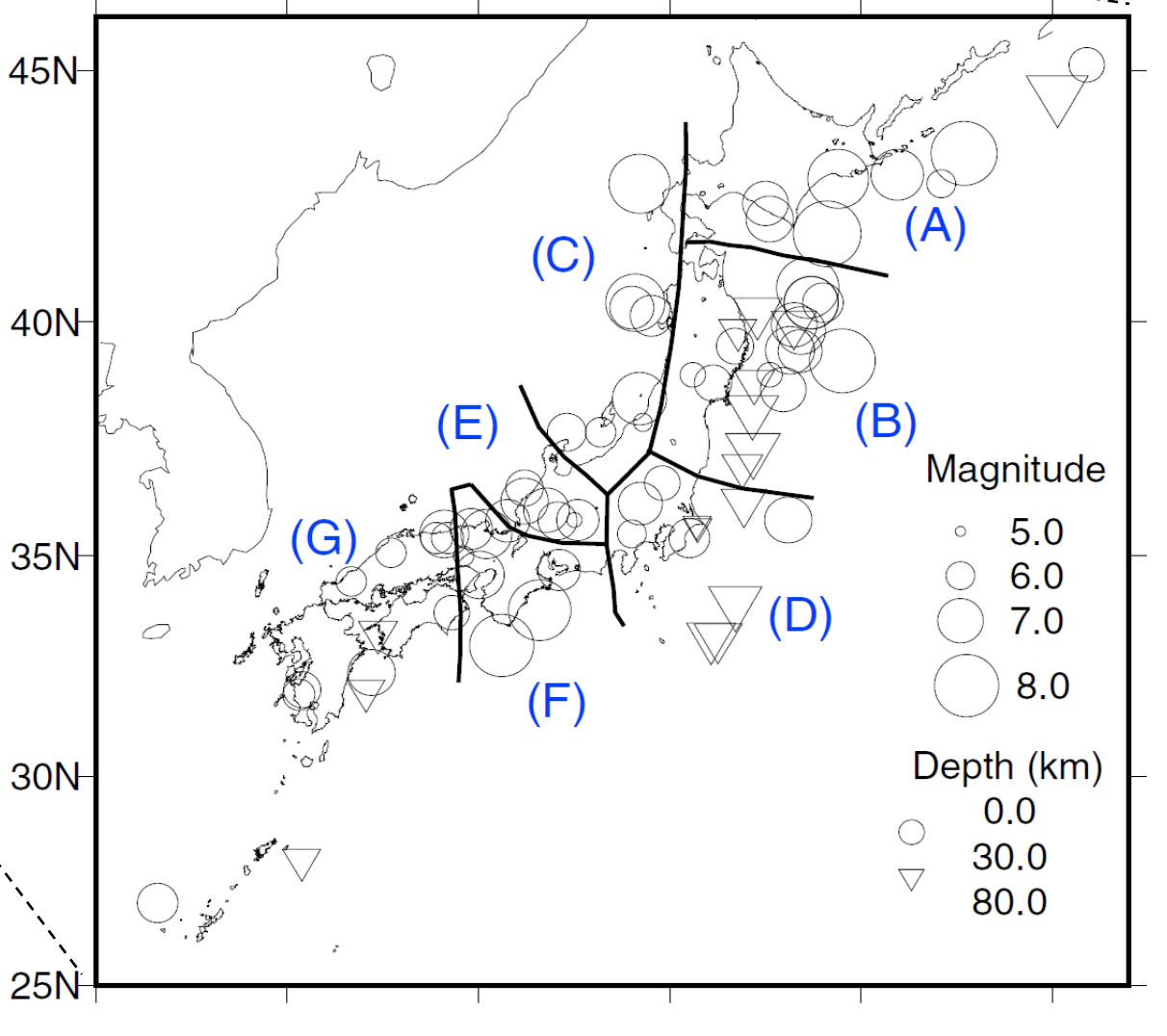
and $k(N)$ is the bias correction in search of t minimizing $AIC_{12}(t)$ (*change-point problem*) and is a certain function of the number of events N in the interval $[S, T]$.

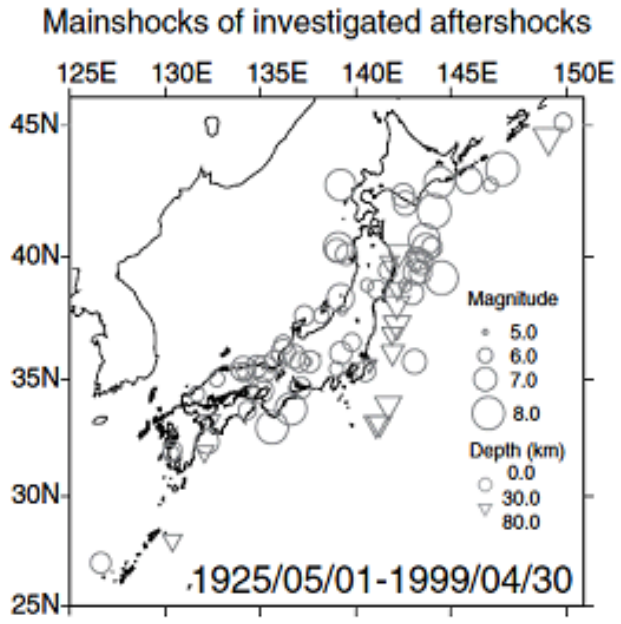

N=522 T=47.880 TO=0.030 T1=5.370
KAGOSHIMA 1997.3/26 - 5/13 M>=2.7
ETAS
1997 Kagoshima NW Earthquake
Relative Quiescence
CUMULATIVE NUMBER OF EARTHQUAKES
MAGNITUDE
TIME
TRANSFORMED TIME
(a)
(b)
K 23.55399
c 0.00247
d 1.82000
P 1.00000
-1956.71
3.15
3.02


n=541 t=773.00 tc=773.00 t0=0.020
95Kobe Aftershocks M0 7.2, Mc 3.0
1995 Kobe Earthquake
(a)
(b)
u
K 49.25900
C 1.88760e-2
α 2.19580
P 1.15670
-2370.18
3.16
3.16
CUMLATIVE NUMBER OF EARTHQUAKES
MAGNITUDE
TIME
TRANSFORMED TIME

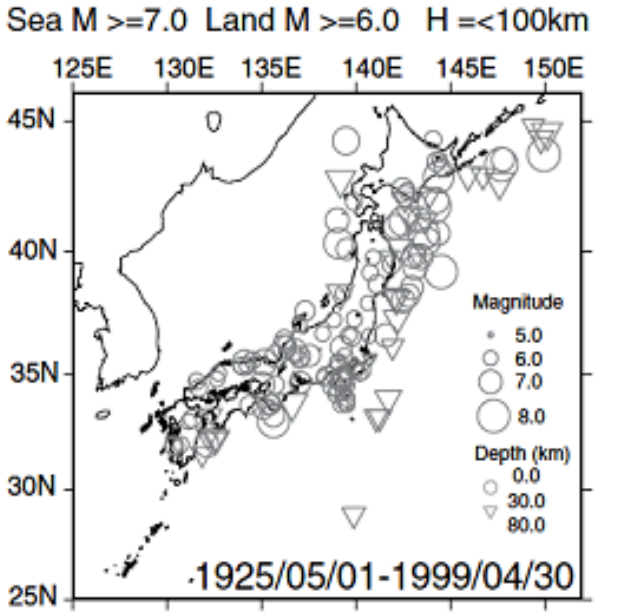
The mainshocks location of investigated Aftershock activity



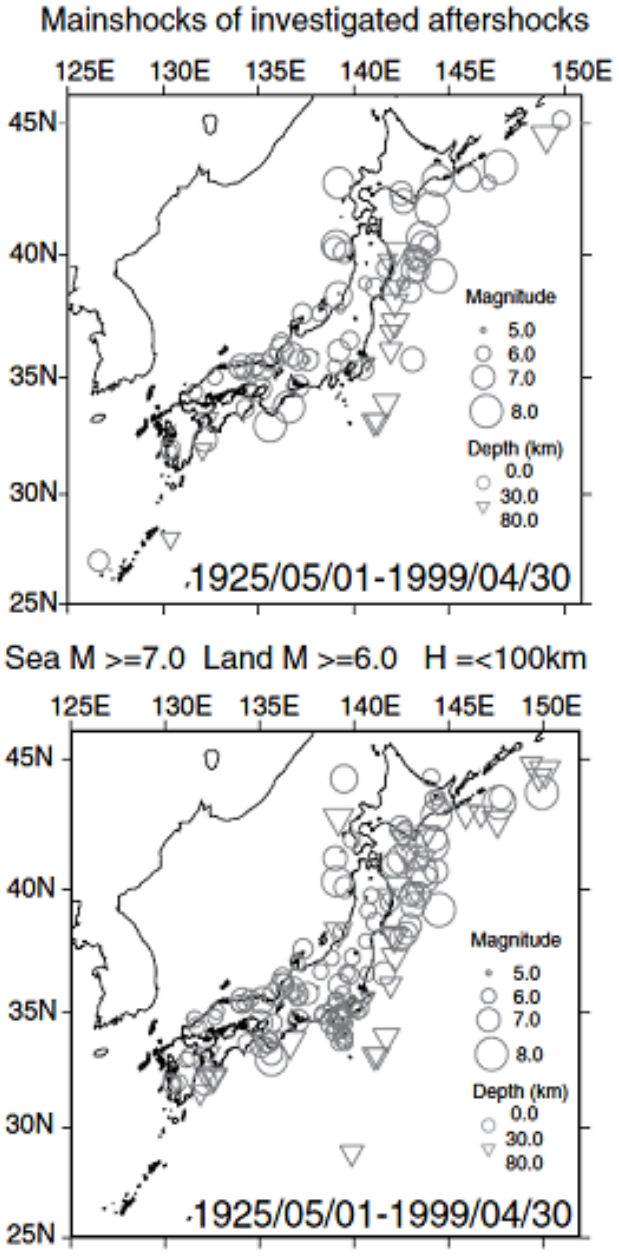


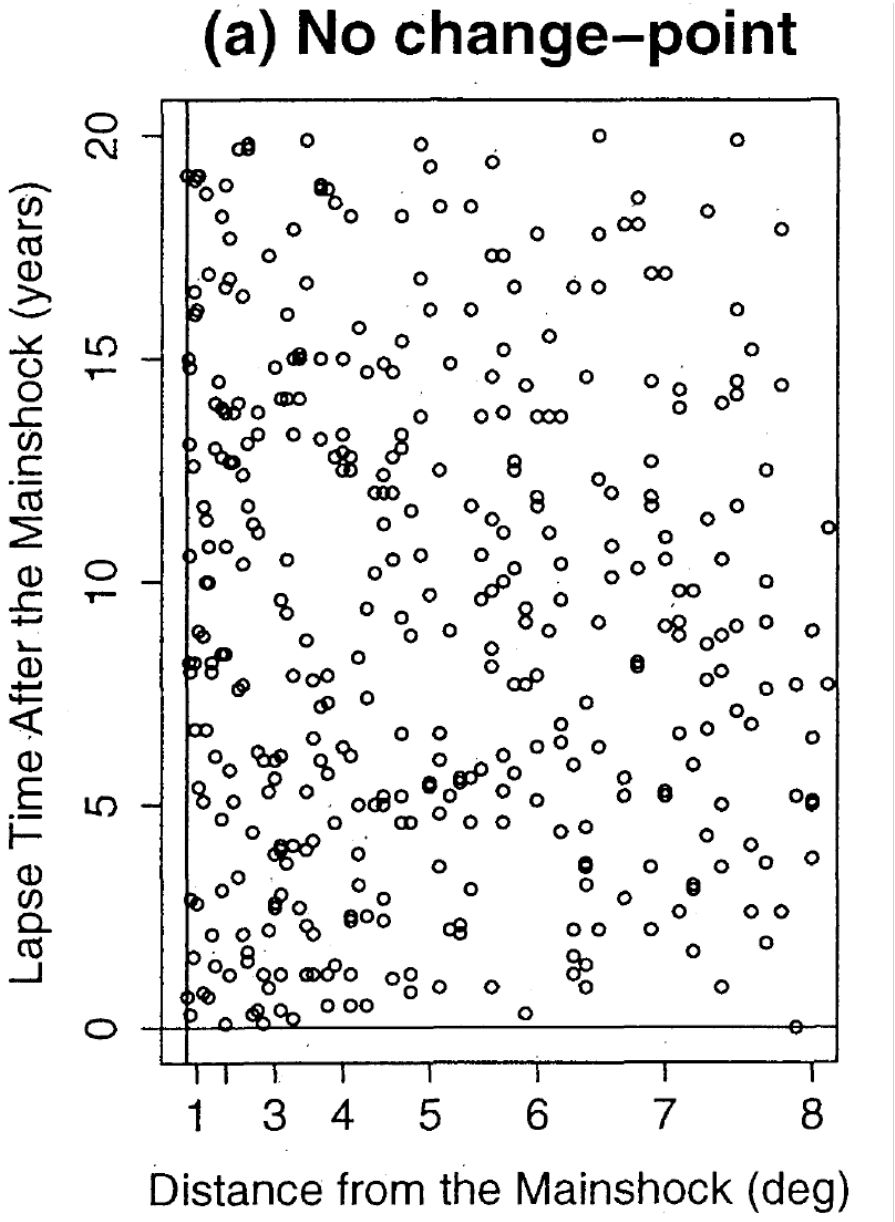


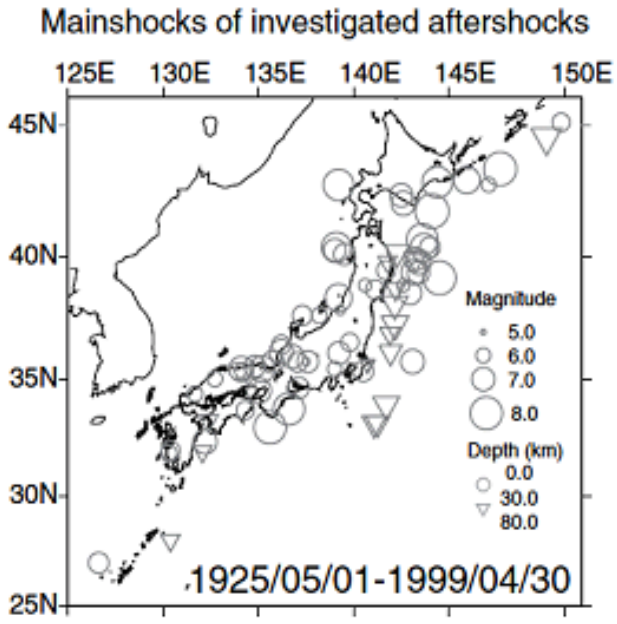
The mainshocks location of investigated Aftershock activity

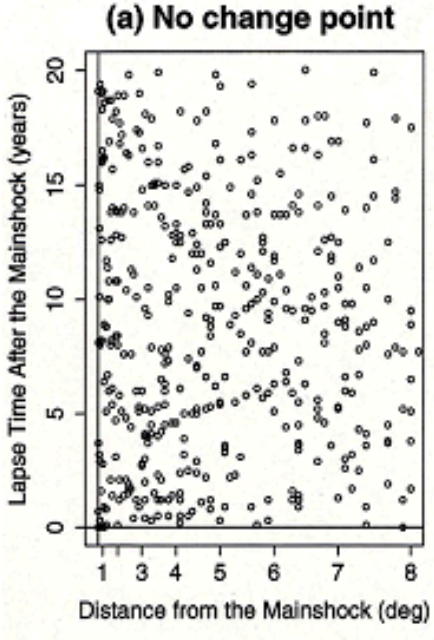


The subsequent large earthquakes

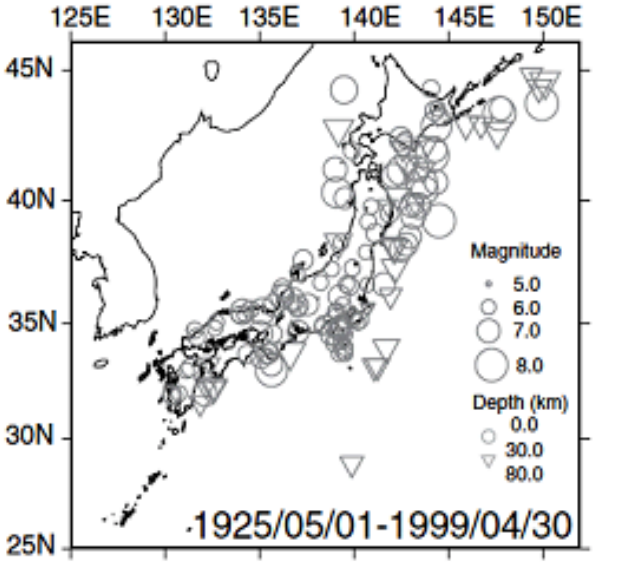

Mainshocks of investigated aftershocks
125E 130E 135E 140E 145E 150E
45N
40N
35N
30N
25N
Magnitude
5.0
6.0
7.0
8.0
Depth (km)
0.0
30.0
80.0
1925/05/01-1999/04/30
Sea M >=7.0 Land M >=6.0 H =<100km
125E 130E 135E 140E 145E 150E
45N
40N
35N
30N
25N
Magnitude
5.0
6.0
7.0
8.0
Depth (km)
0.0
30.0
80.0
1925/05/01-1999/04/30

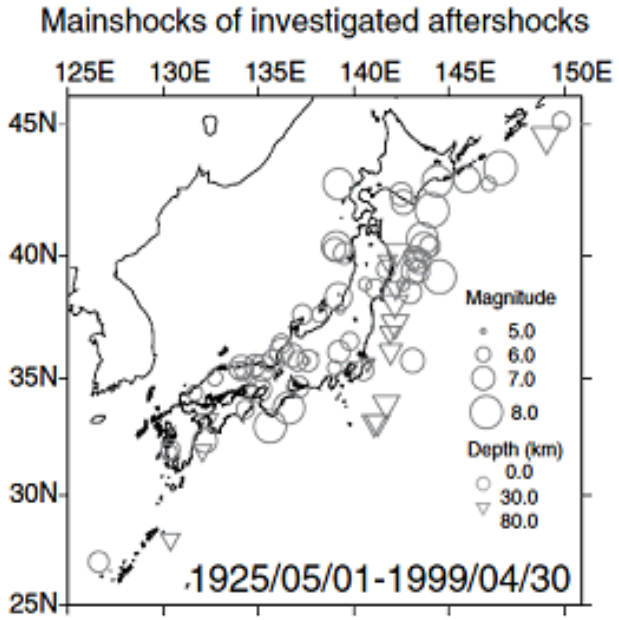

(a) No change–point
Lapse Time After the Mainshock (years)
0
5
10
15
20
1
3
4
5
6
7
8
Distance from the Mainshock (deg)



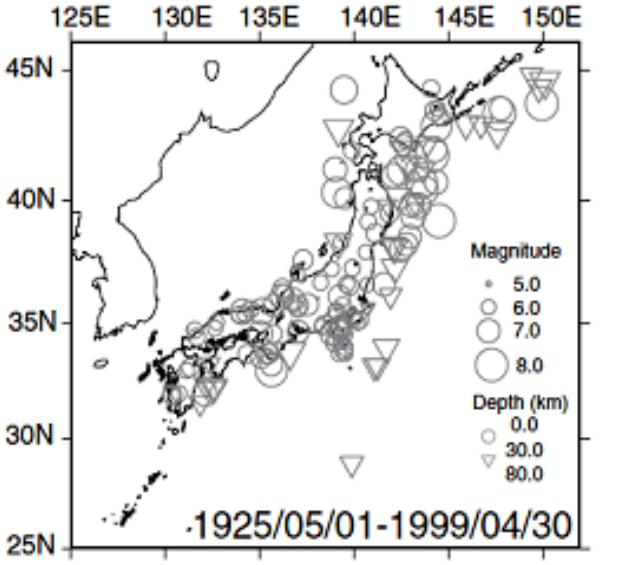


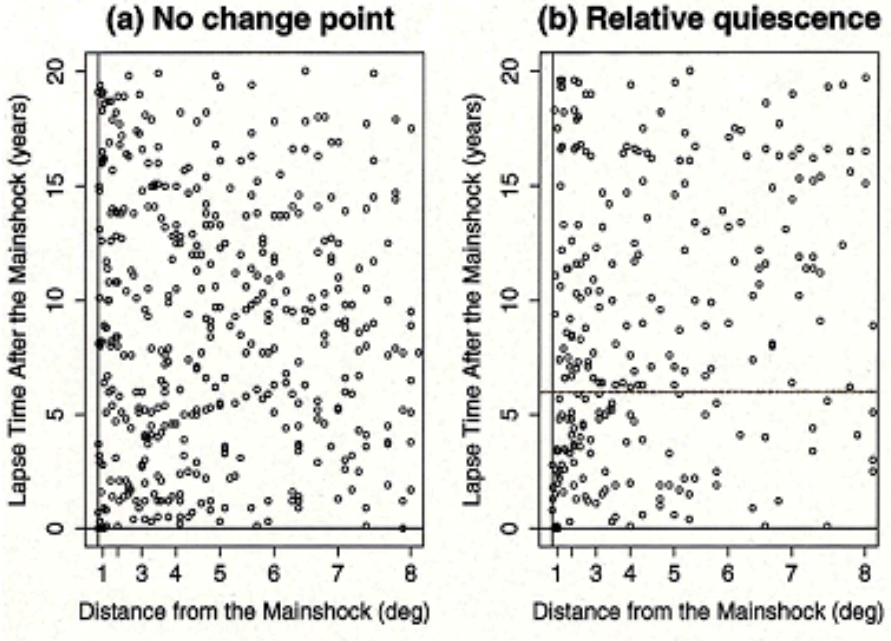
Sea M >=7.0 Land M >=6.0 H =<100km

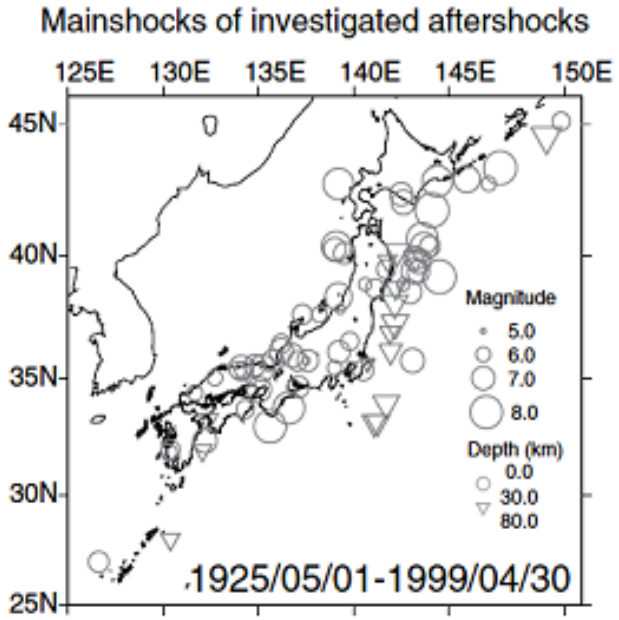




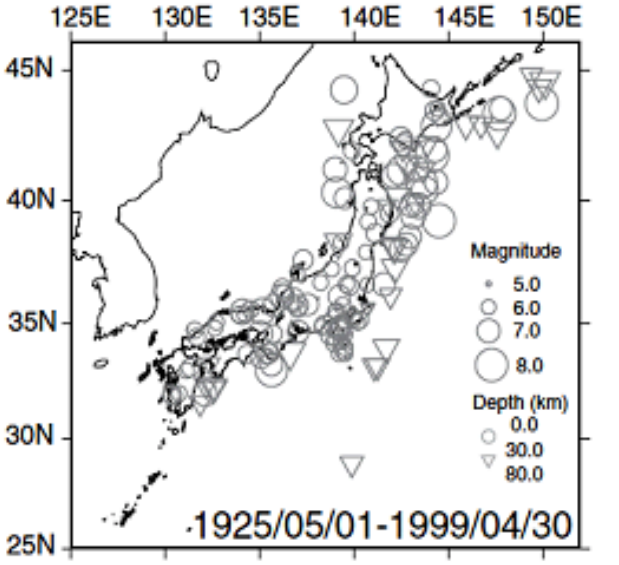
Sea M >=7.0 Land M >=6.0 H =<100km

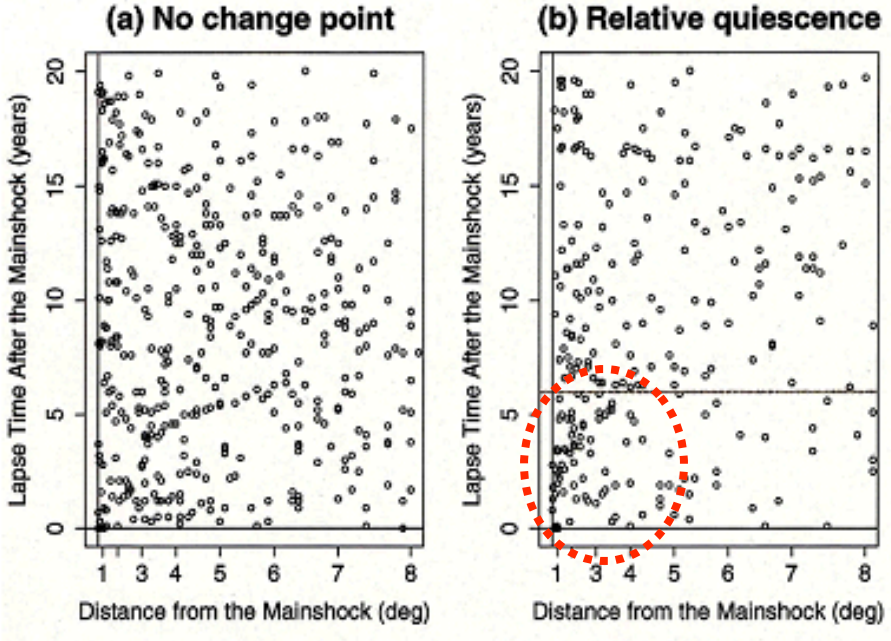


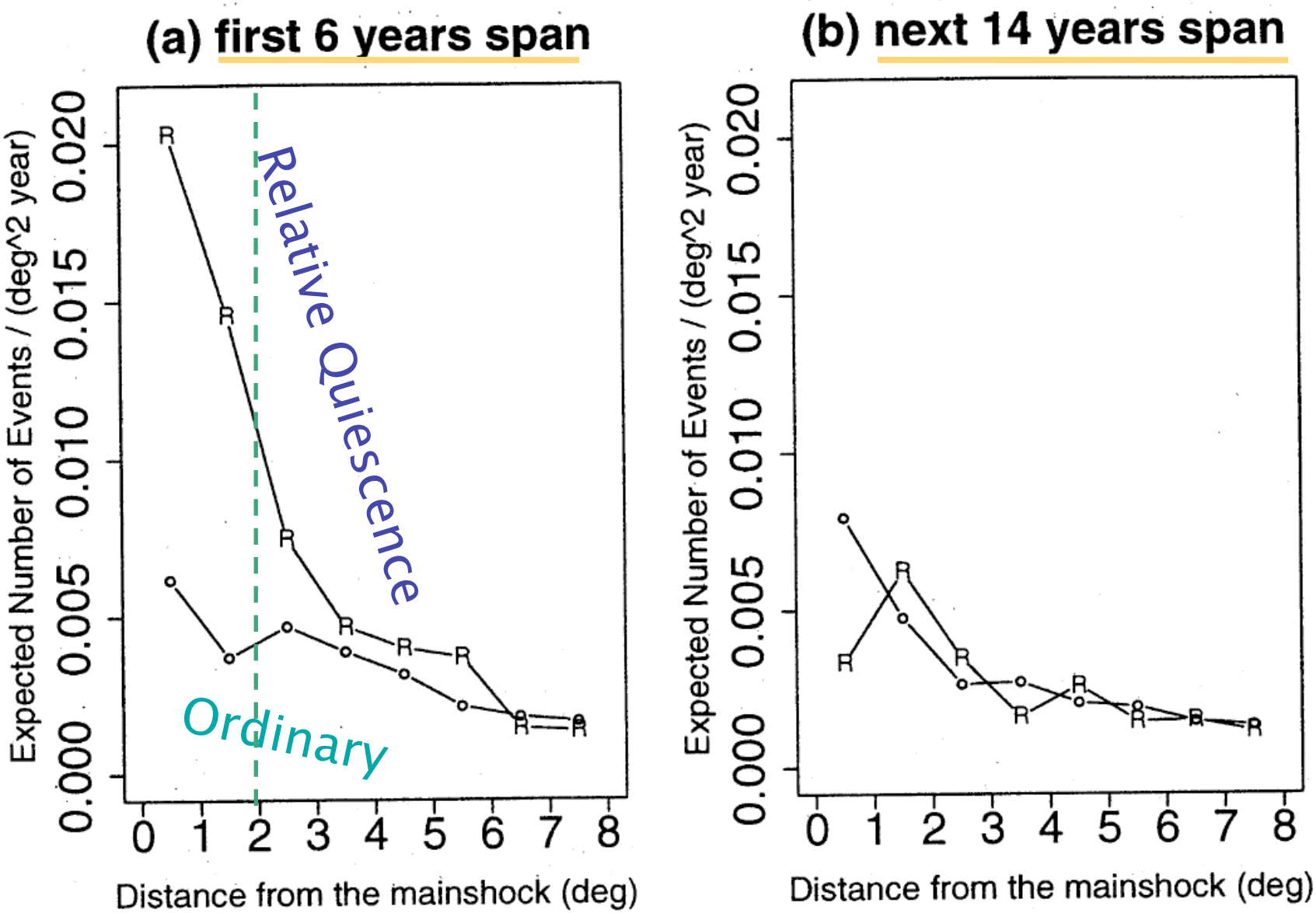




Sea M >=7.0 Land M >=6.0 H =<100km






(a) first 6 years span
(b) next 14 years span
Expected Number of Events / (deg^2 year)
0.000
0.005
0.010
0.015
0.020
0 1 2 3 4 5 6 7 8
Distance from the mainshock (deg)
Relative Quiescence
Ordinary
R

Proposed possible mechanisms of precursory seismic quiescence

- Dilatancy hardening [*Kelleher and J. Savino*, 1975]
- Bi-modal asperity model [*Kanamori*, 1981]
- Stress weakening due to a creep [*Wyss et al.*, 1981]
- Slip-weakening [*Cao and Aki*, 1985]
- Computer simulations
  [*Mikumo and Miyatake*, 1983; *Hainzl et al.*, 2000].

→ Mechanism within the source

Seismic Quiescence

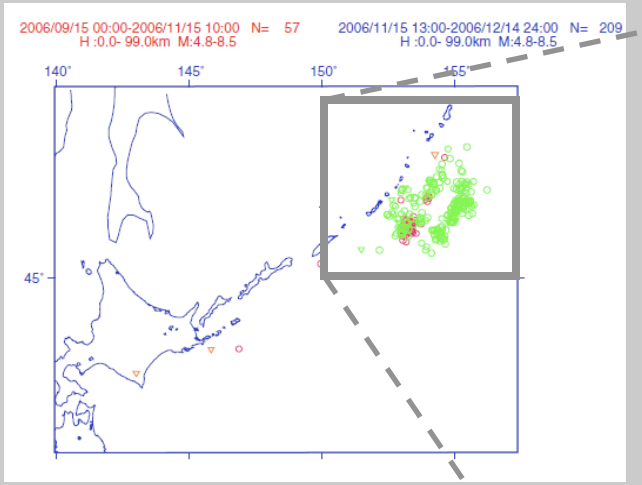
- **Reports**: Inoue (1965), Utsu (1968), Mogi (1969), Ohtake et al. (1977), Wyss (1986), Kisslinger (1986), etc., about 200 papers
- **Significantly wider area than the source**: Inoue (1965), Motoya (1987), Ogata (1988, 1992, 1999)
- **Simulation based on rate- and state-dependent friction law:** Kato, Ohtake and Hirasawa (1997)

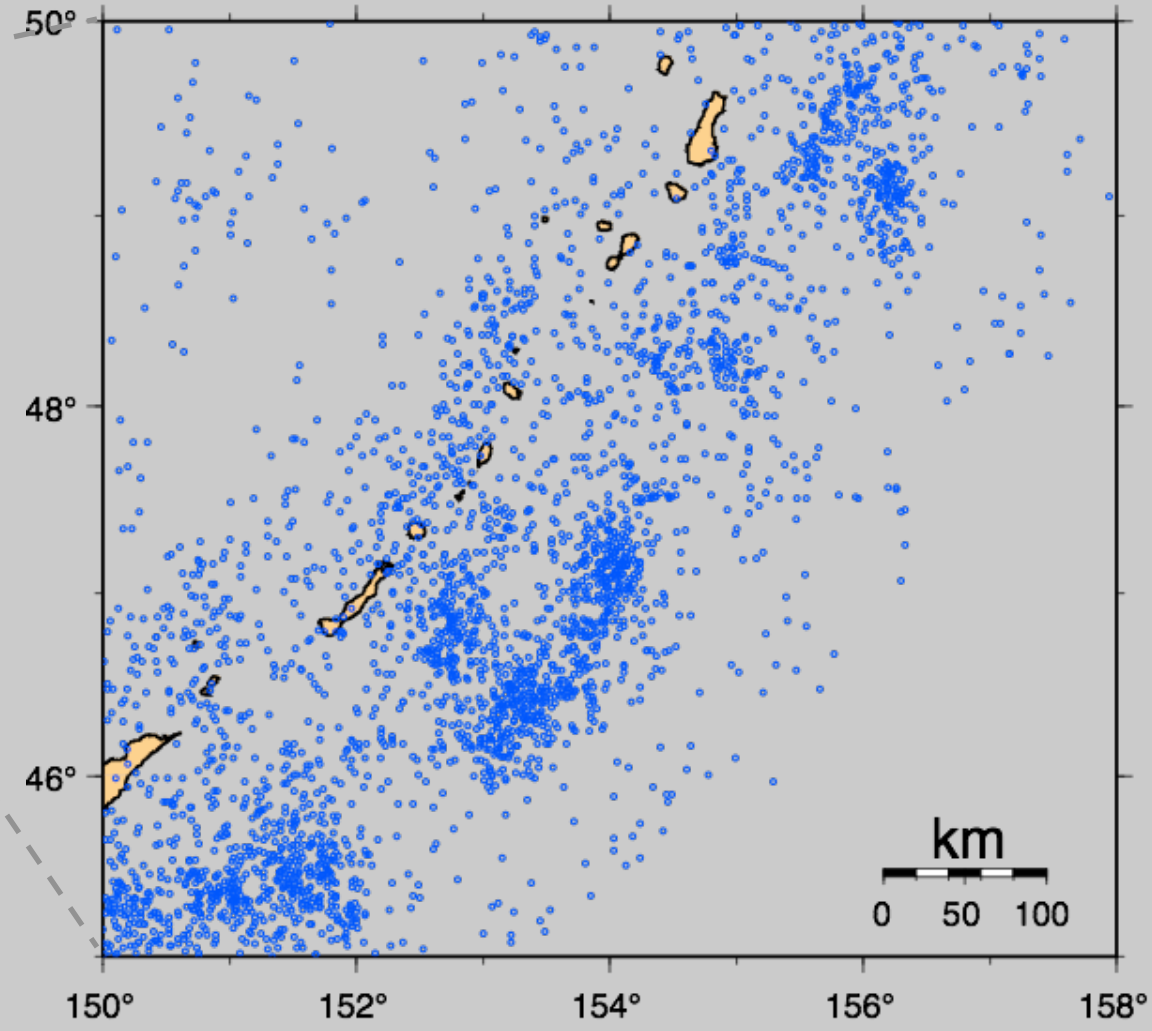
The November 2006 and January 2007 Kuril Earthquakes

Collaborative with Shinji Toda)

Background seismicity off Kuril Island and aftershocks of the November 2006 great earthquake of M8.3

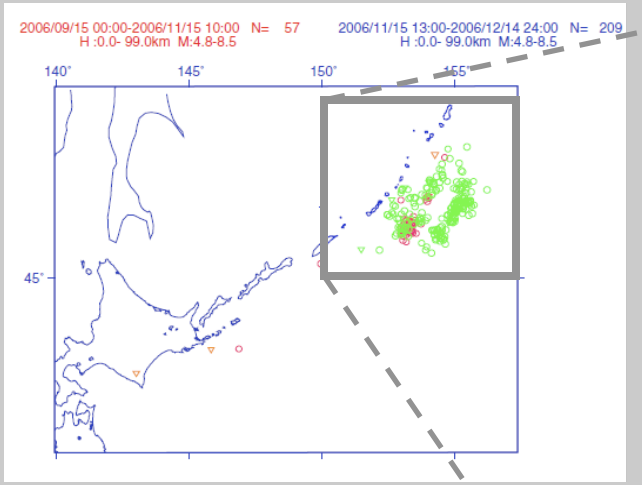
USGS/NEIC 1973-2006.11.14

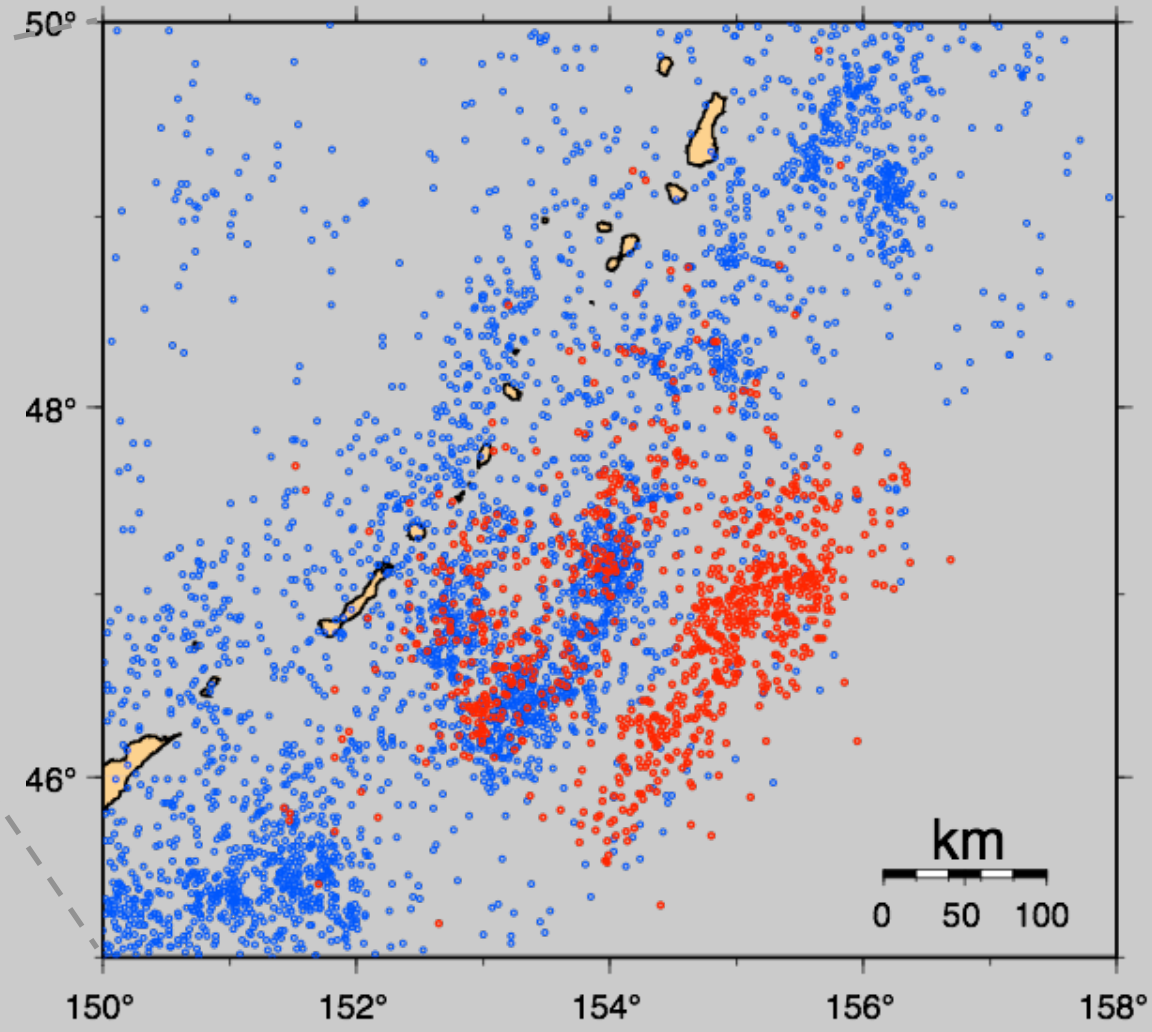




Background seismicity off Kuril Island and aftershocks of the November 2006 great earthquake of M8.3

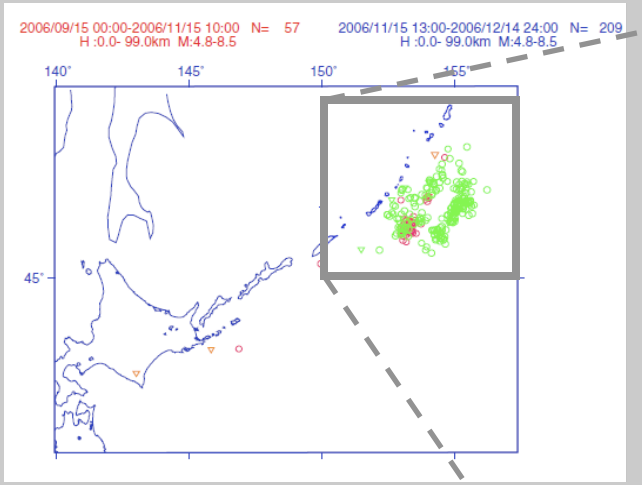
USGS/NEIC 1973-2006.11.14 2006.11.15-2007.1.13

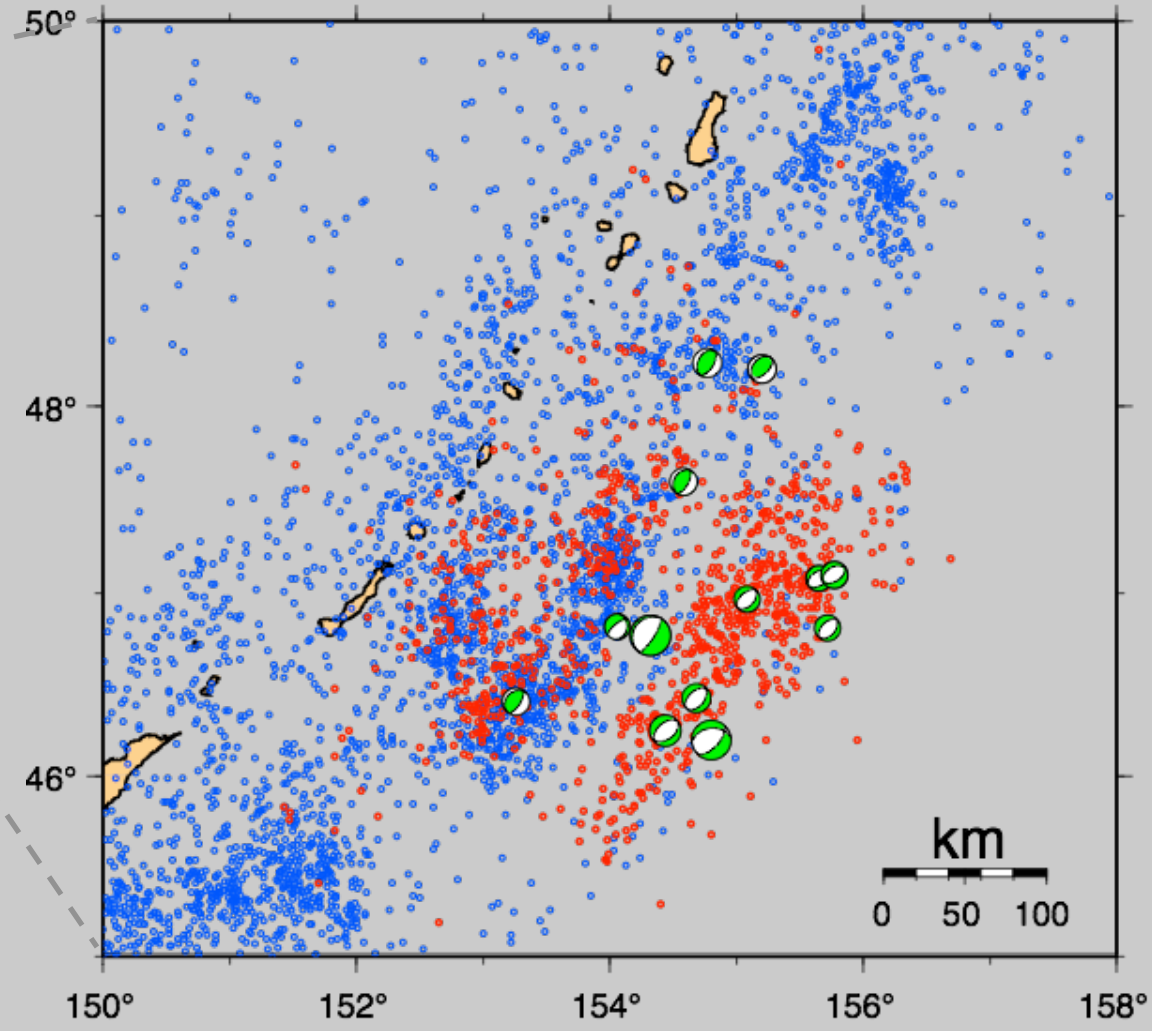




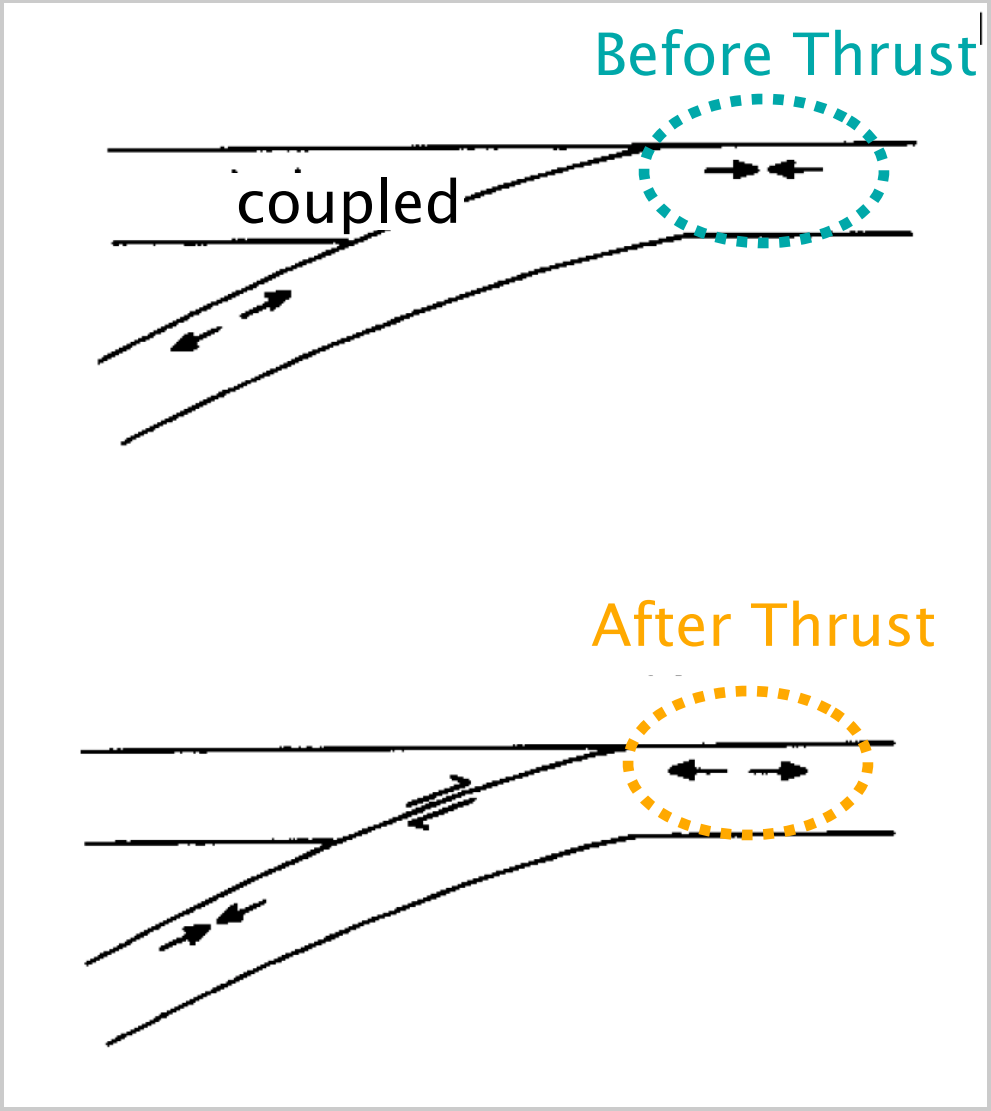
Background seismicity off Kuril Island and aftershocks of the November 2006 great earthquake of M8.3

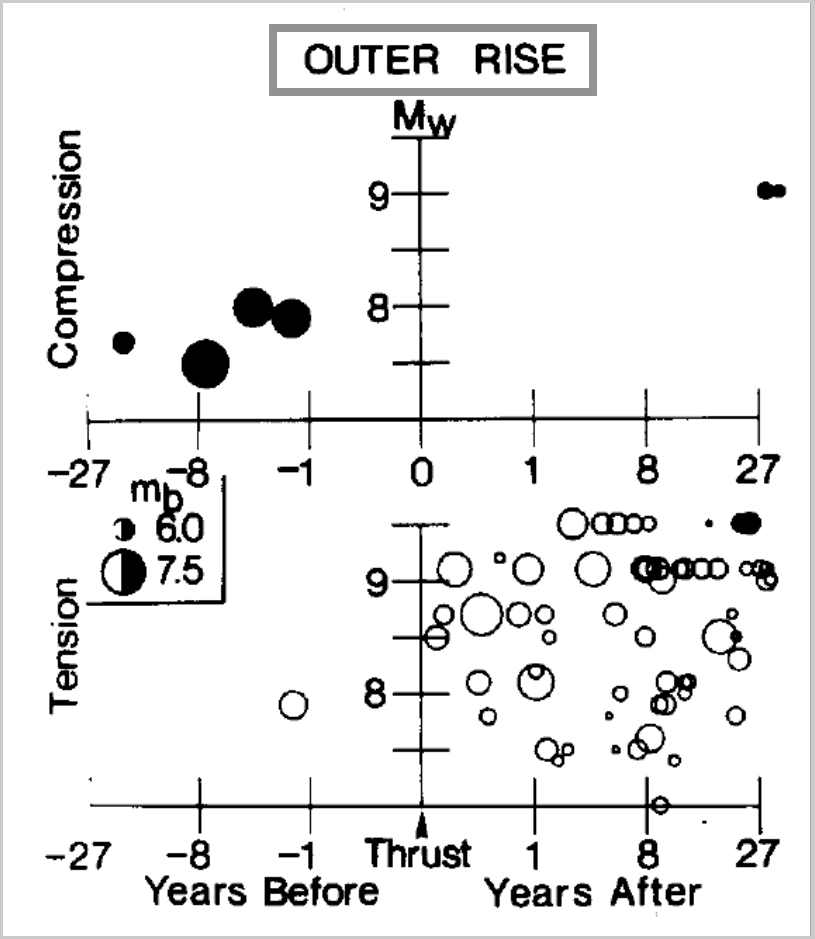
USGS/NEIC 1973-2006.11.14 2006.11.15-2007.1.13





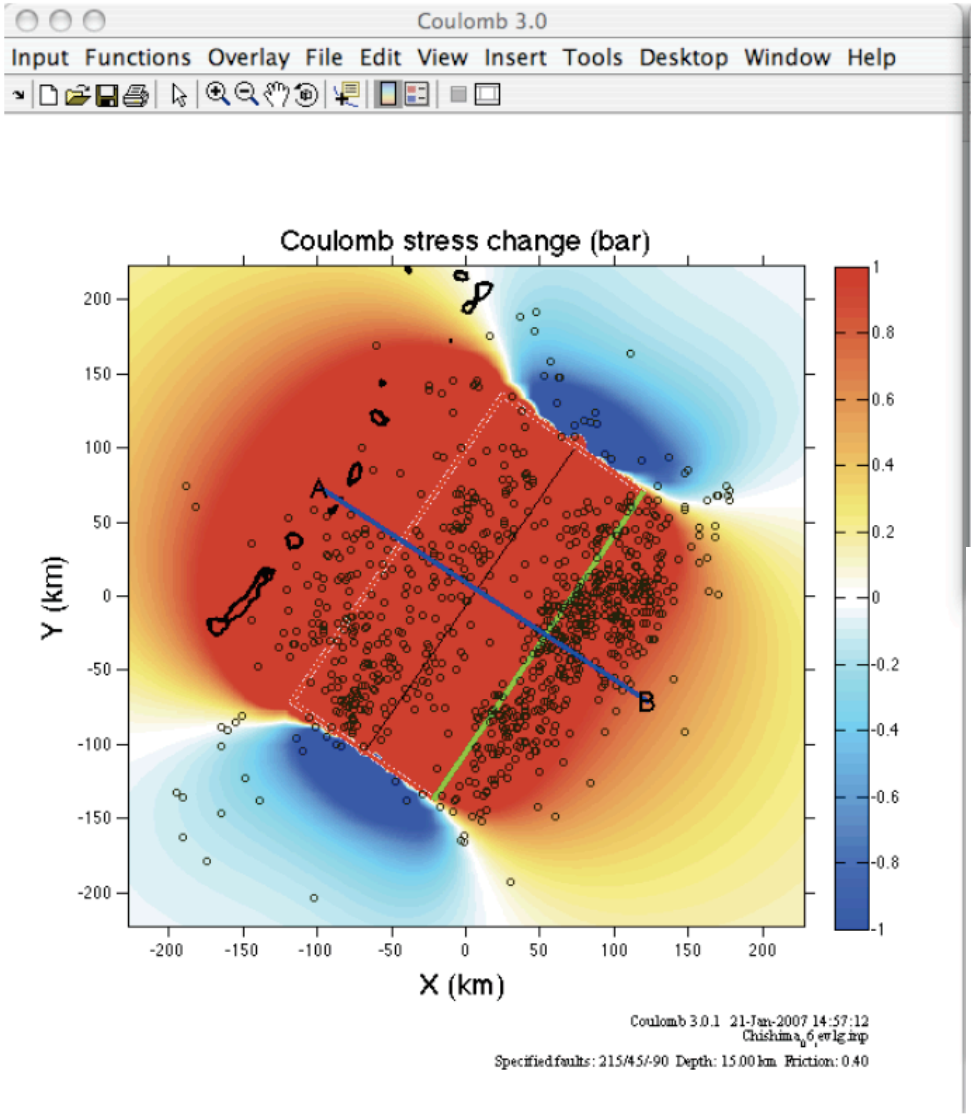
Lay, Astiz, Kanamori and Christensen, 1989, PEPI

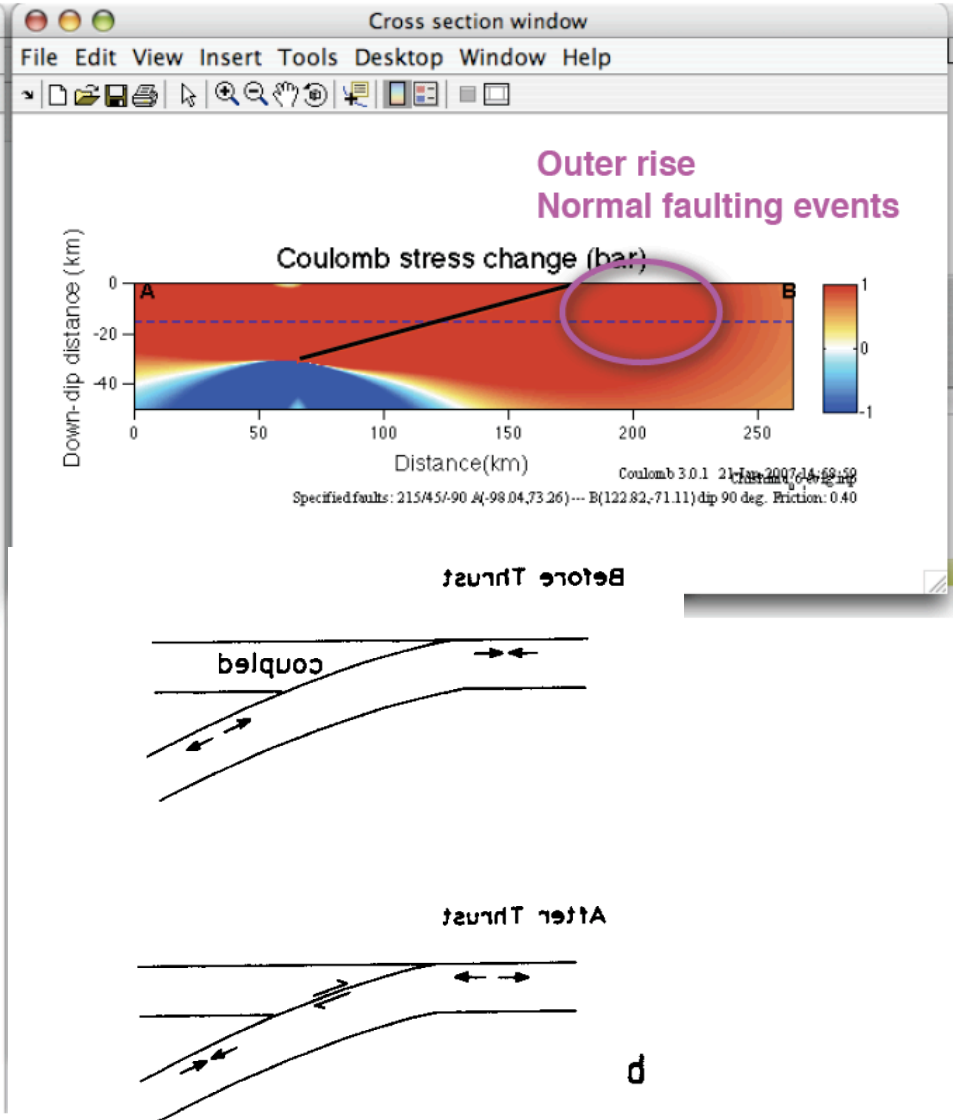




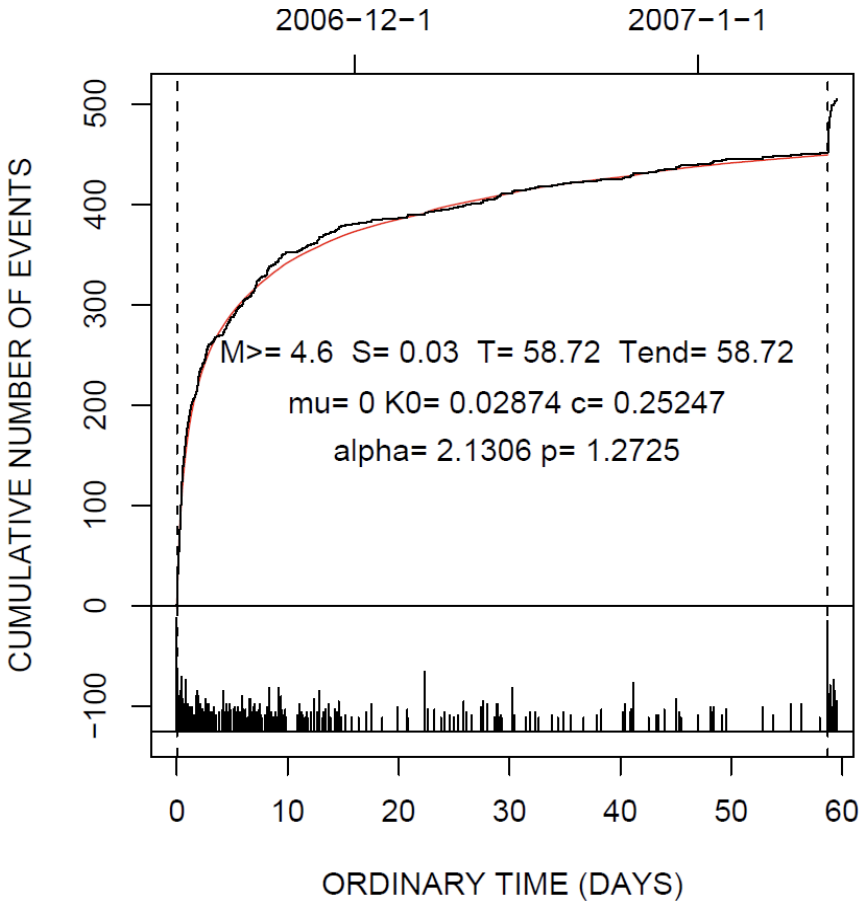
2006年11月15日千島列島東方海溝型地震による周辺正断層へのクーロン応力変化

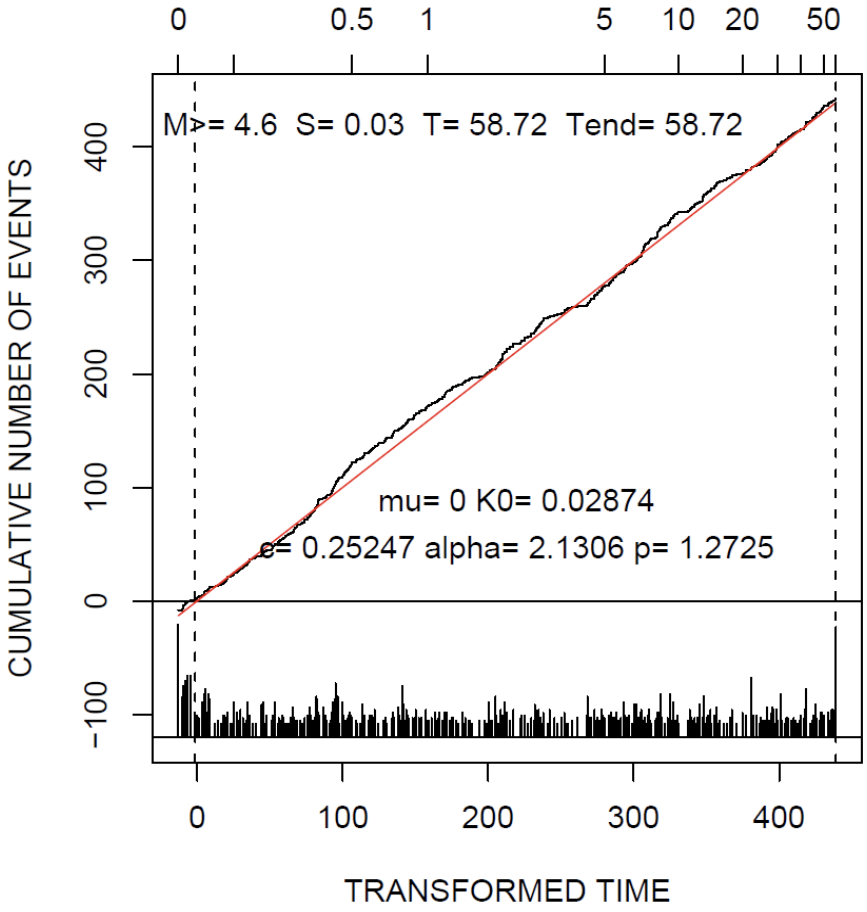
Coulomb 3.0 (Toda, Stein, Lin & Sevilgen)　による計算結果

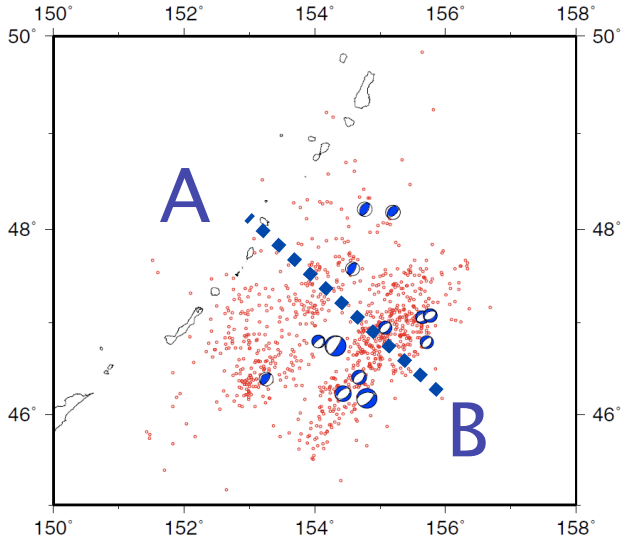




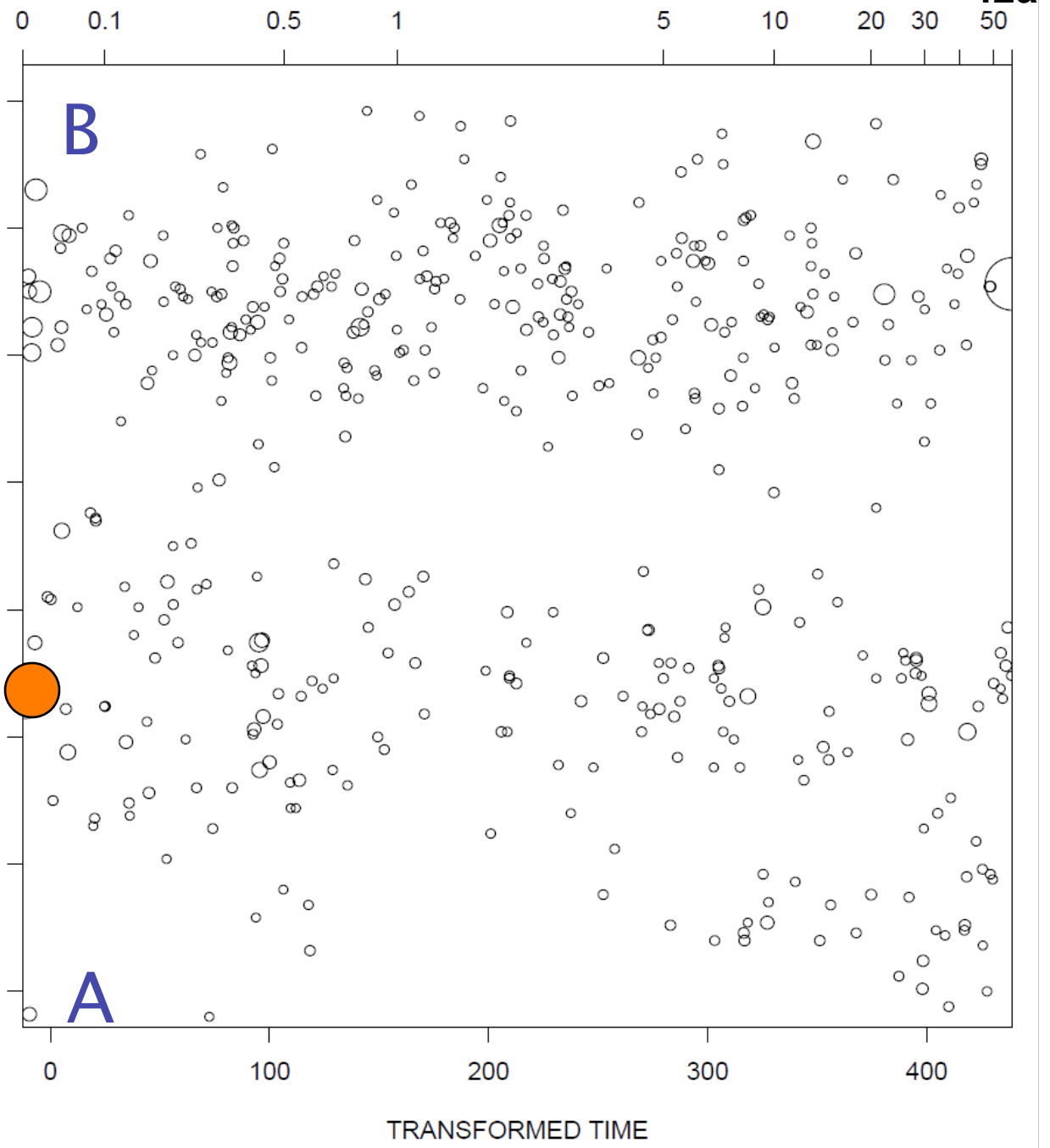
Aftershock activity of 15Nov2006 event （M8.3）

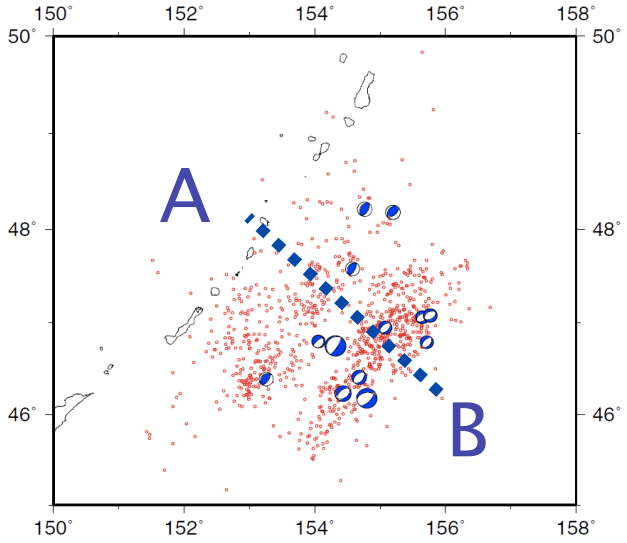




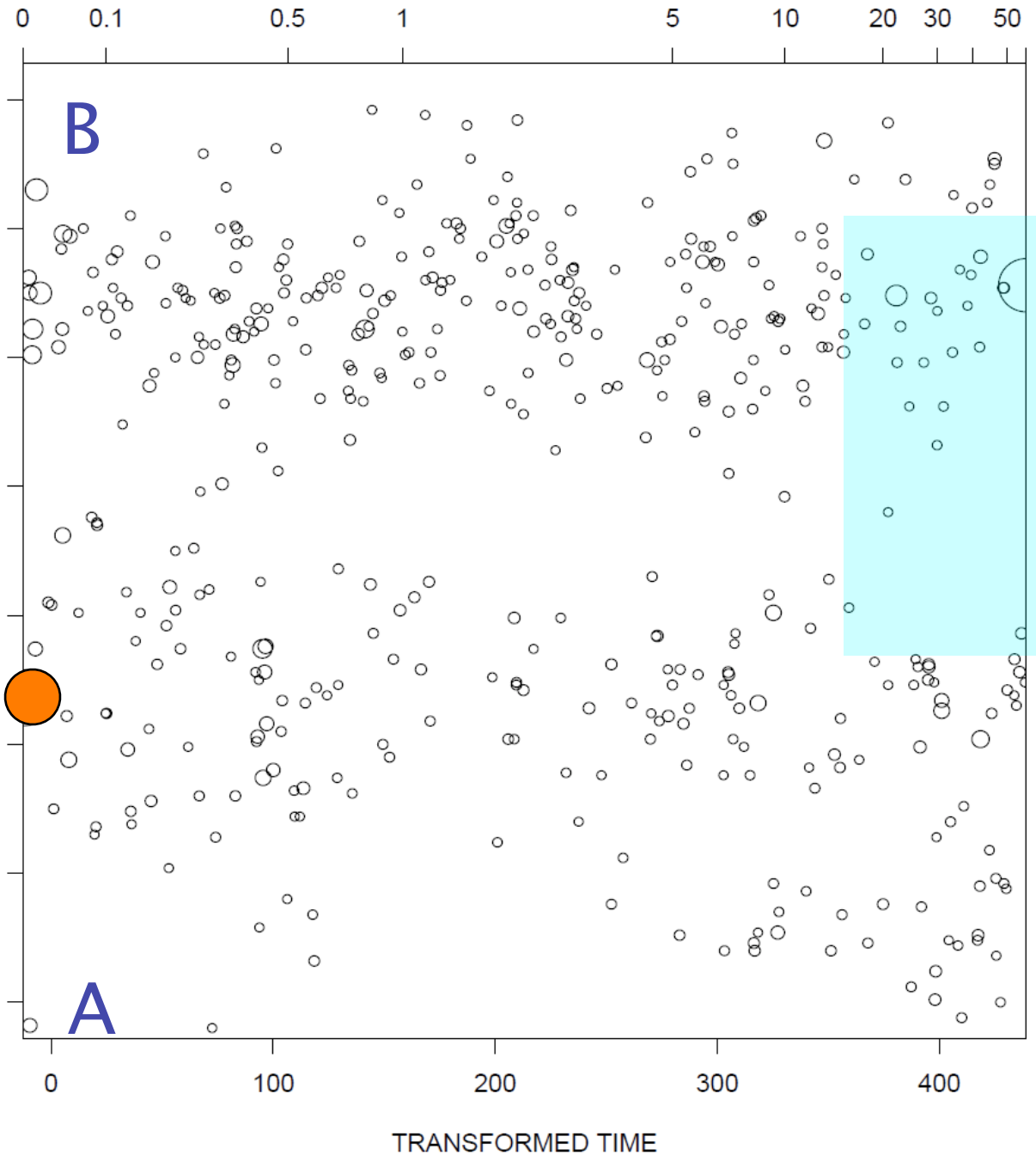

150°
152°
154°
156°
158°
50°
48°
46°
A
B

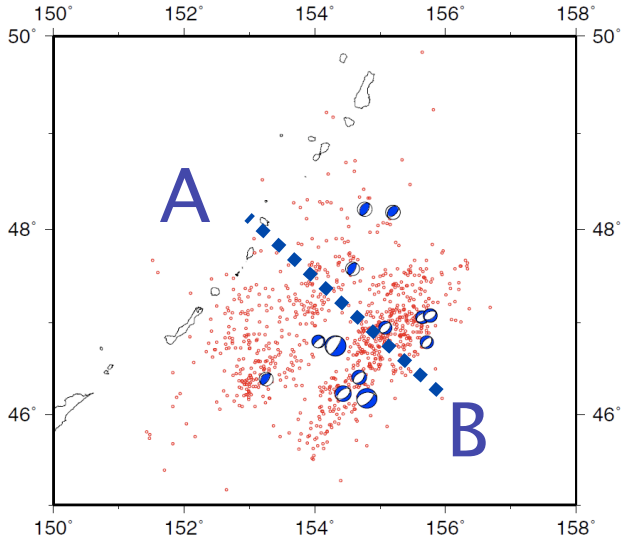
M >= 4.6


0
0.1
0.5
1
5
10
20
30
50
B
A
0
100
200
300
400
TRANSFORMED TIME

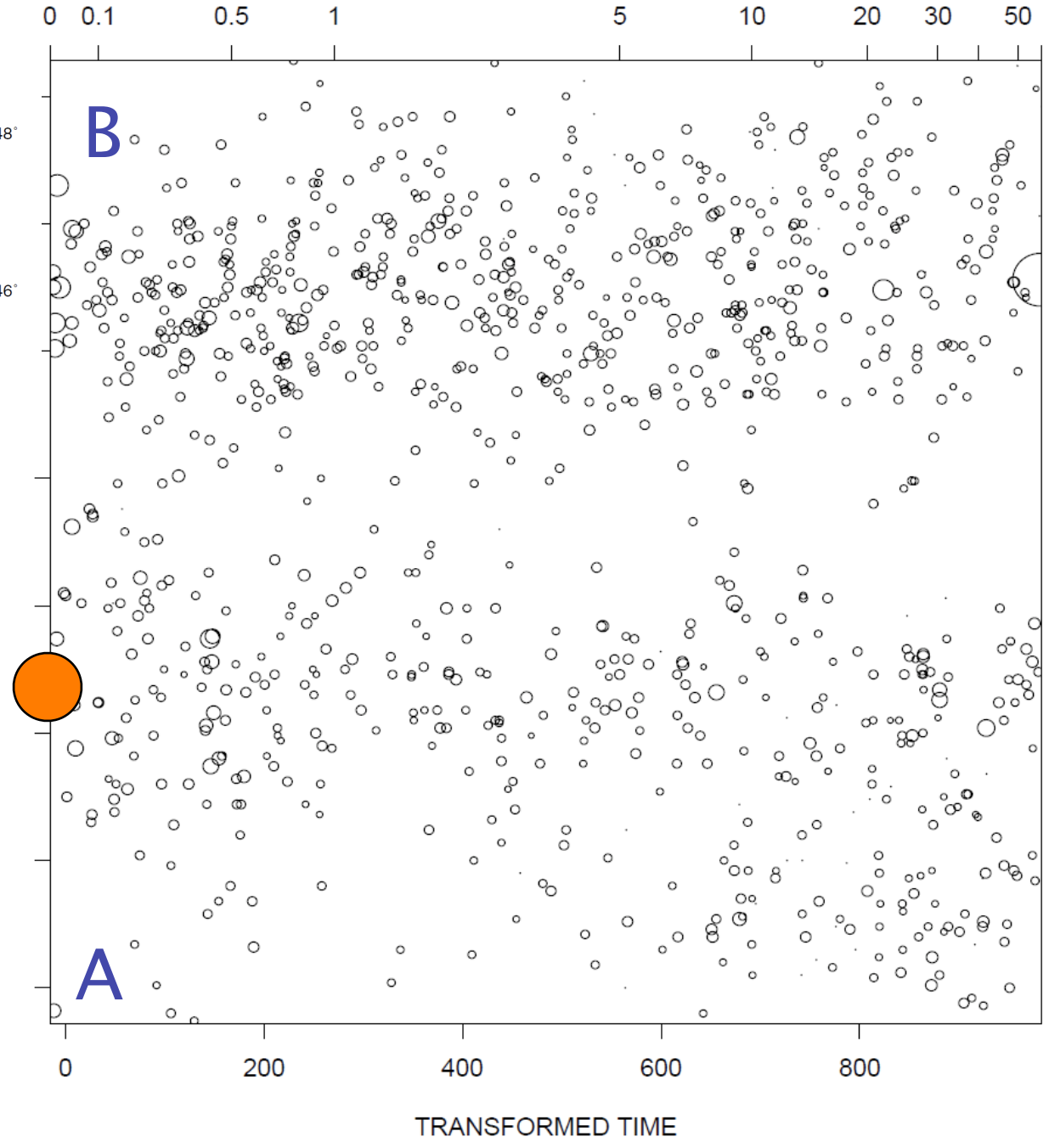

150°
152°
154°
156°
158°
50°
48°
46°
A
B

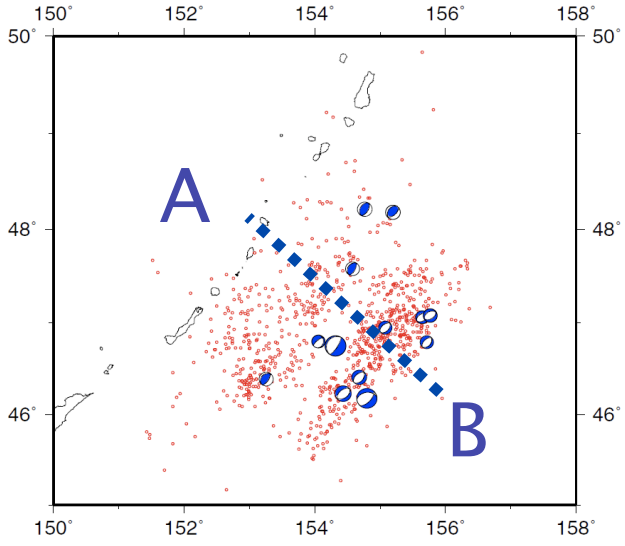
M >= 4.6


0
0.1
0.5
1
5
10
20
30
50
B
A
0
100
200
300
400
TRANSFORMED TIME

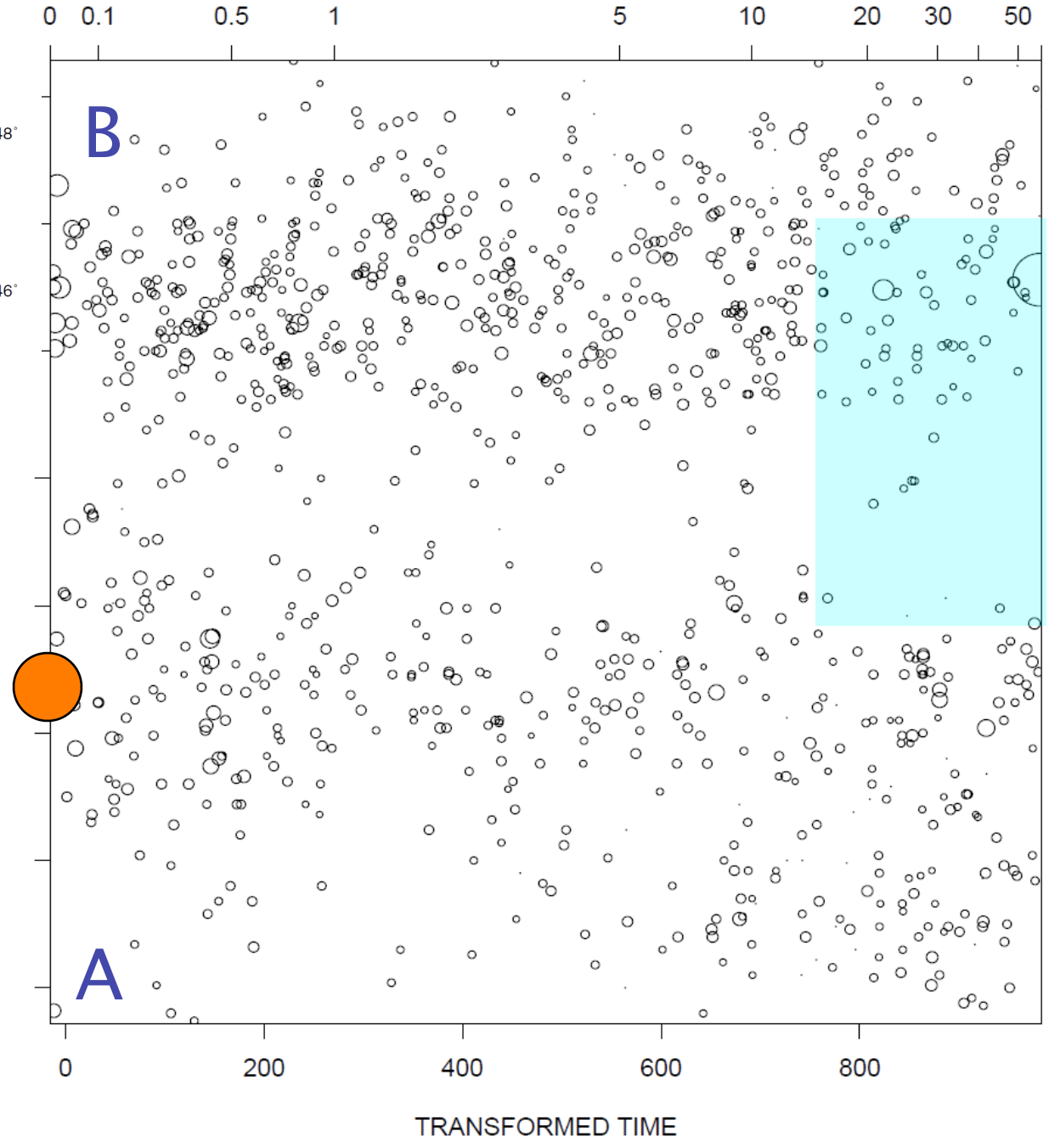


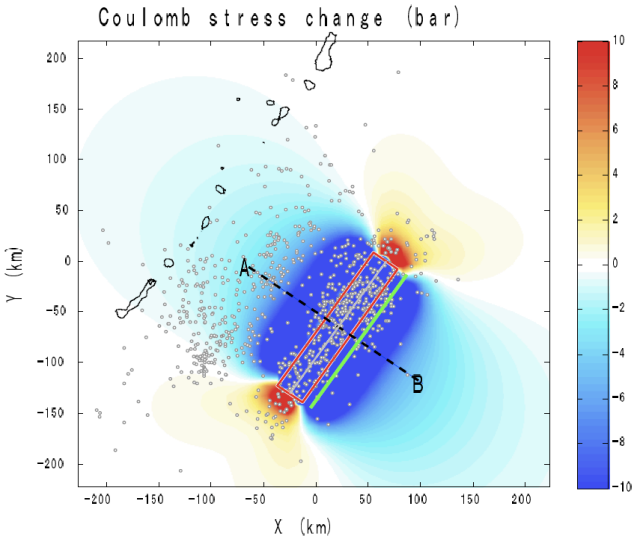
All detected events

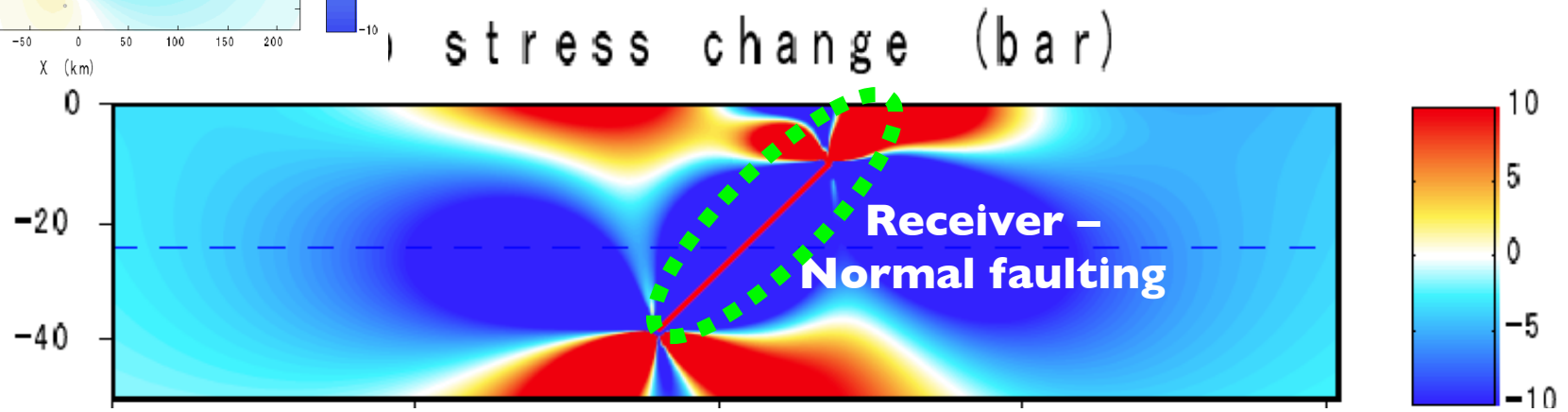




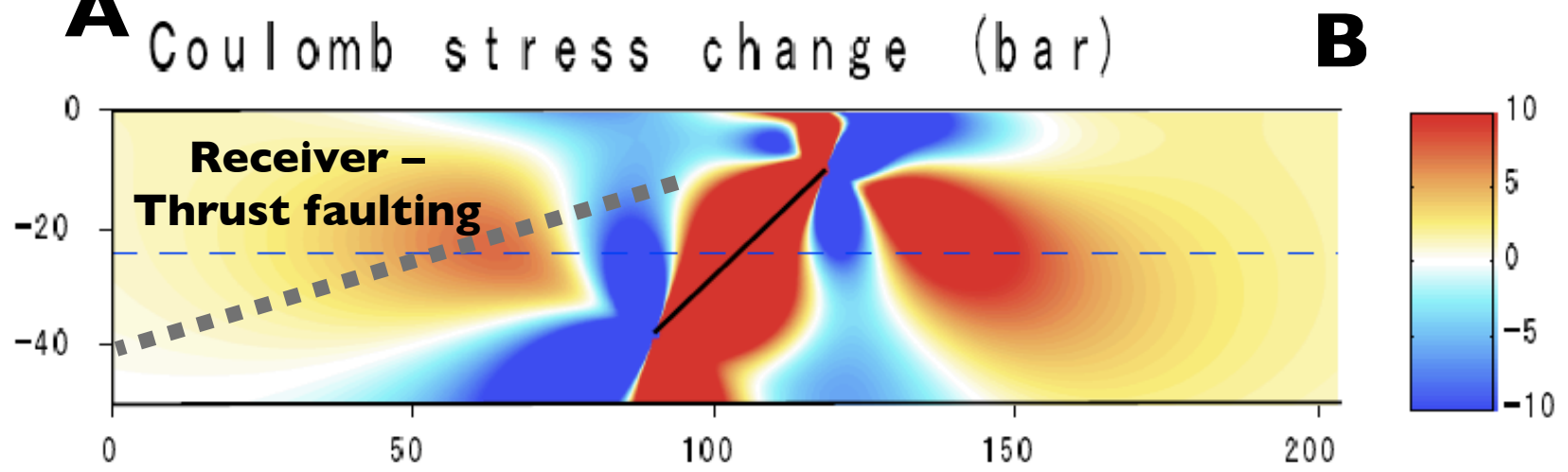
All detected events




Coulomb stress change (bar)
A
B
Y (km)
X (km)


stress change (bar)
Receiver –
Normal faulting

A

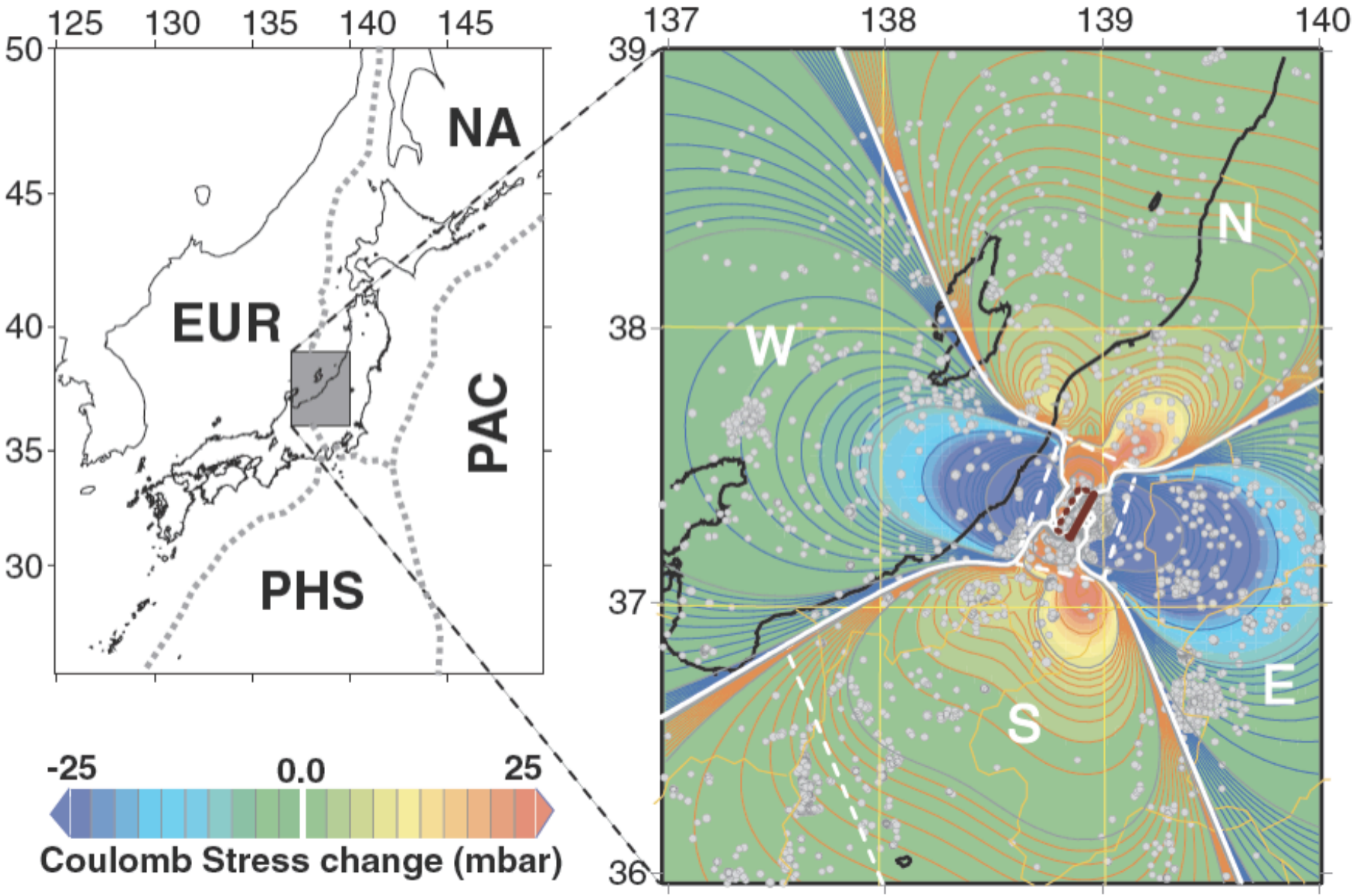

Coulomb stress change (bar)
Receiver –
Thrust faulting

B

The 2004 Chuetsu Earthquake

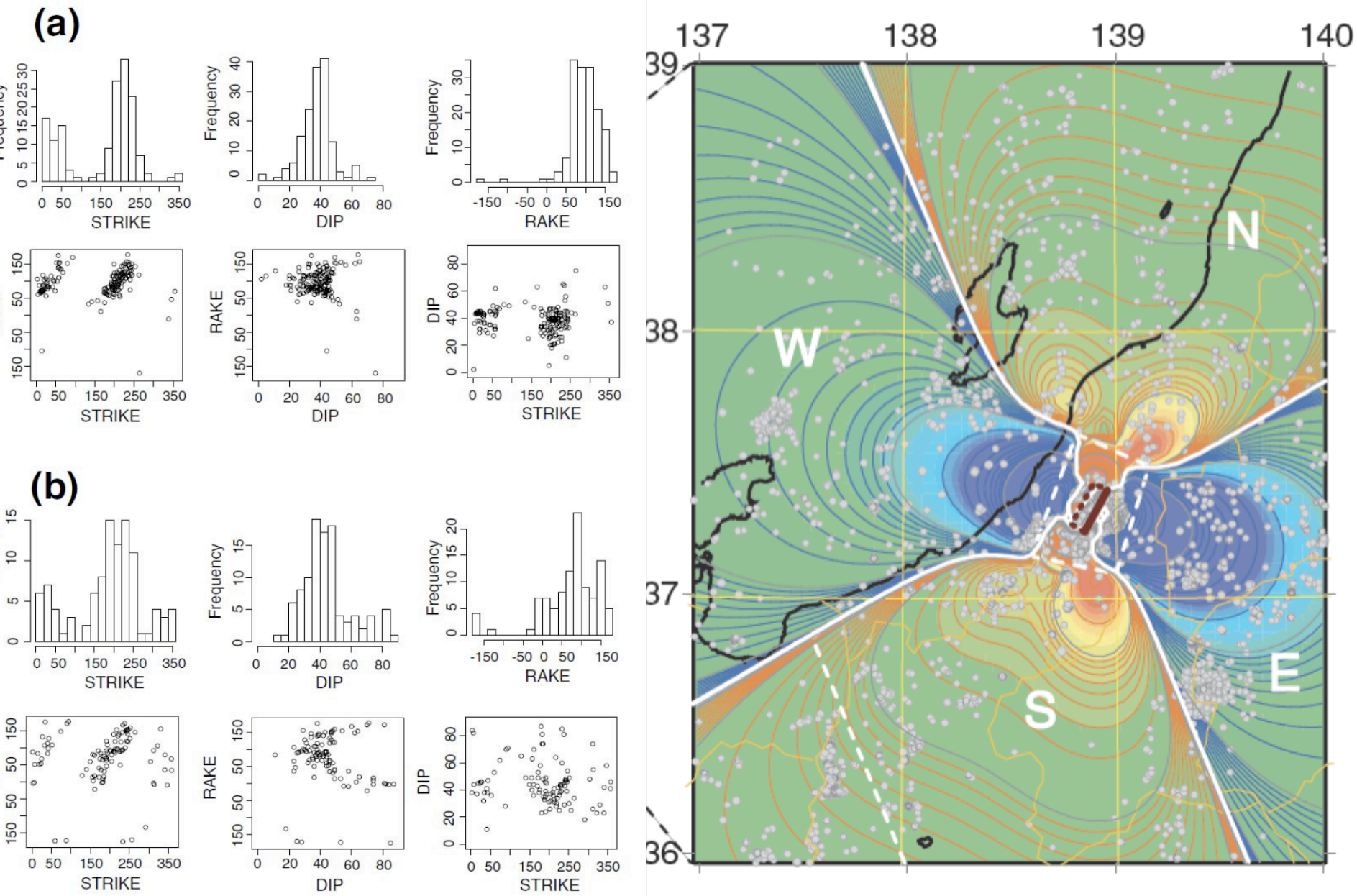
1997/01/01 - 2004/10/30 Number of events = 4060

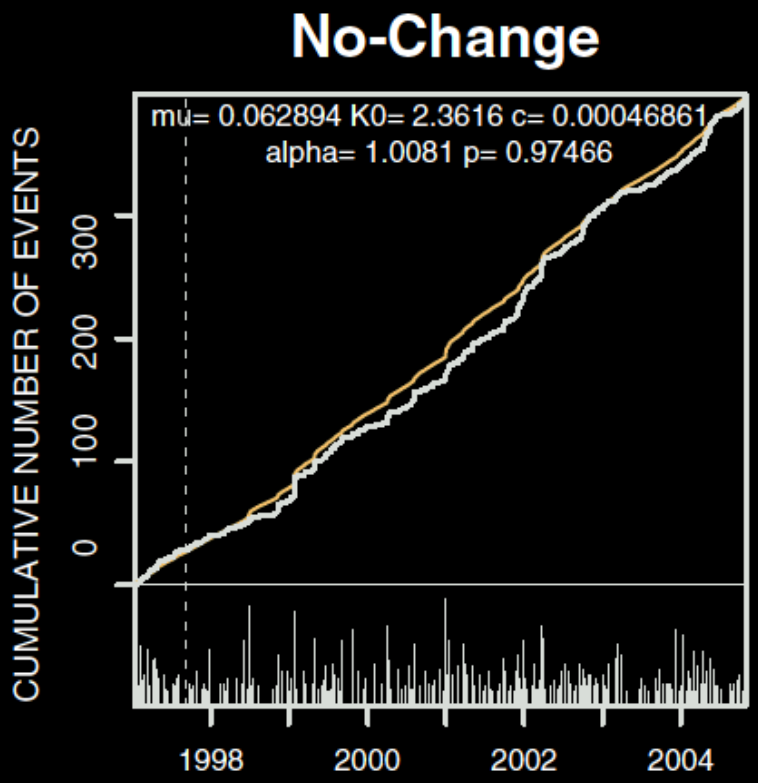
Depth =< 25.0 km, M >= 2.0



1997/01/01 - 2004/10/30 Number of events = 4060

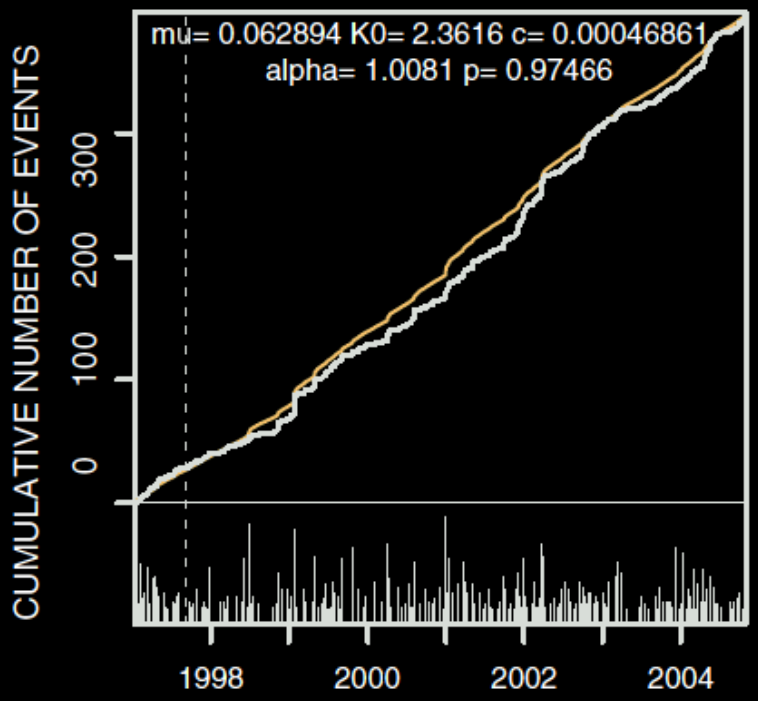
Depth =< 25.0 km, M >= 2.0

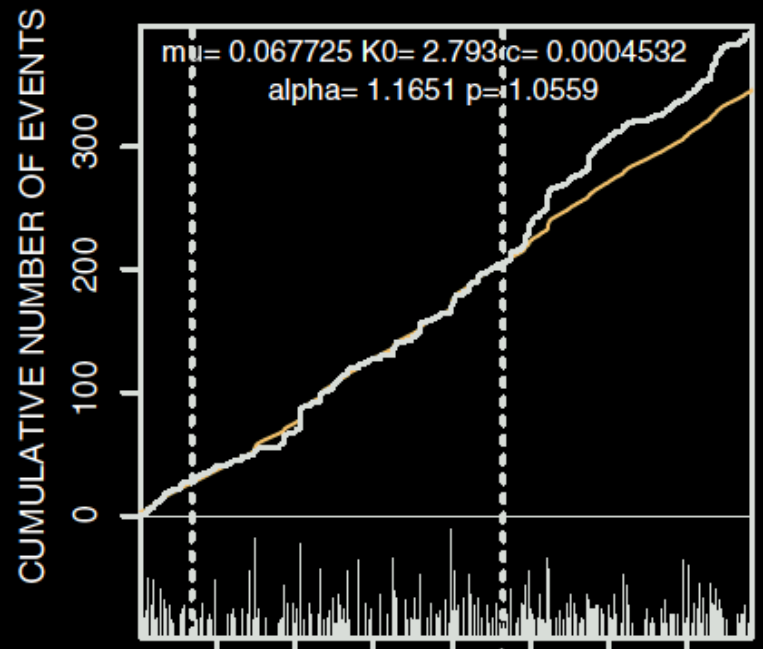


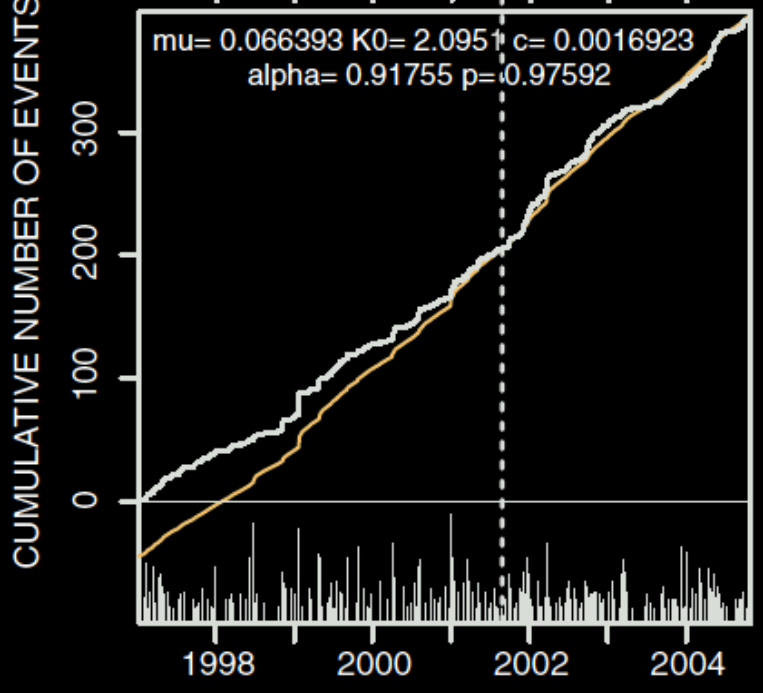

No-Change
mu= 0.062894 K0= 2.3616 c= 0.00046861
alpha= 1.0081 p= 0.97466
CUMULATIVE NUMBER OF EVENTS
0
100
200
300
1998
2000
2002
2004

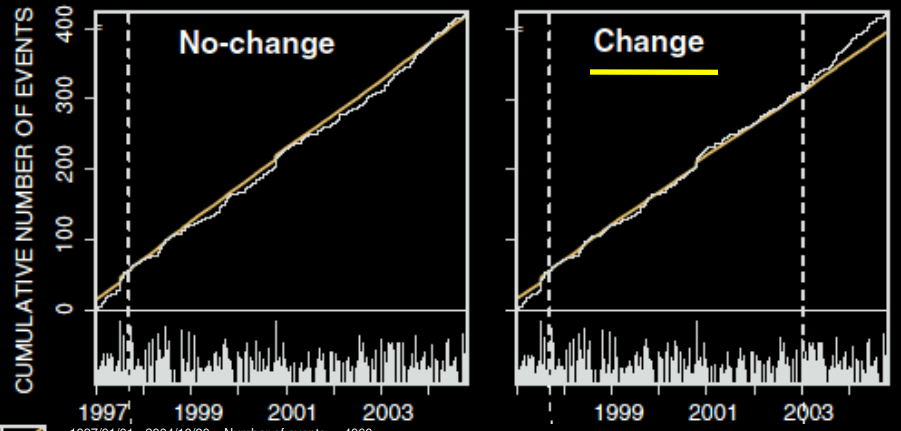
A Change

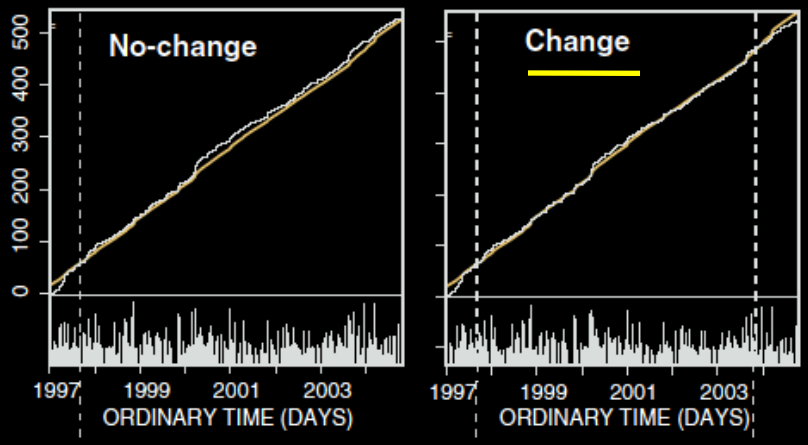
No-Change

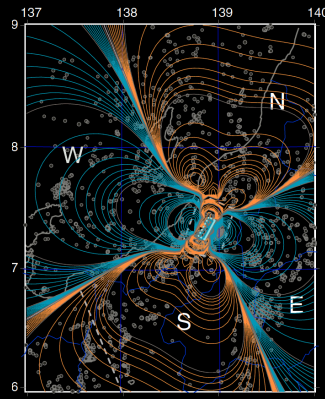


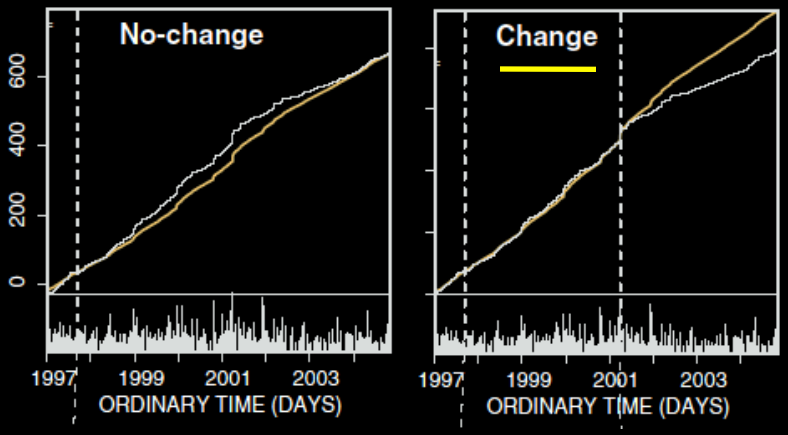


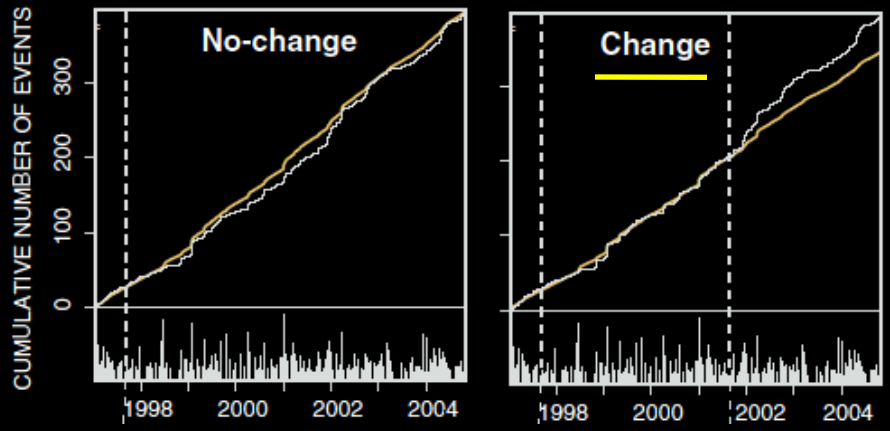


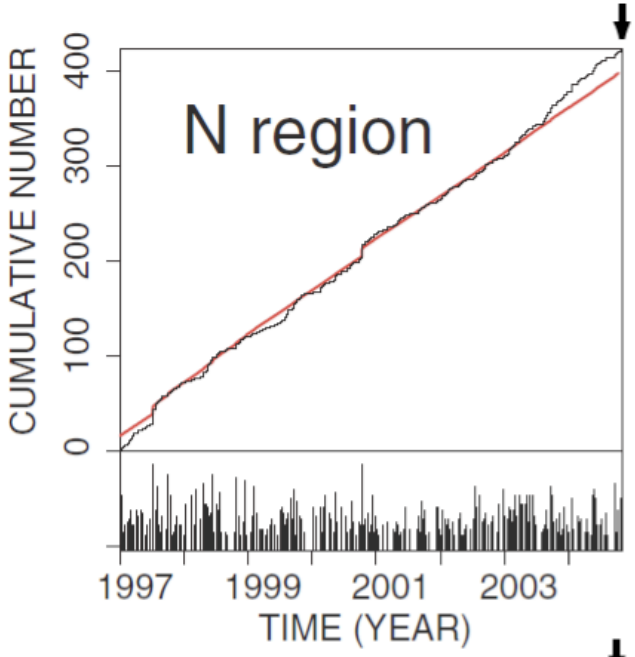

No-change
Change
CUMULATIVE NUMBER OF EVENTS
0
100
200
300
400
1997
1999
2001
2003

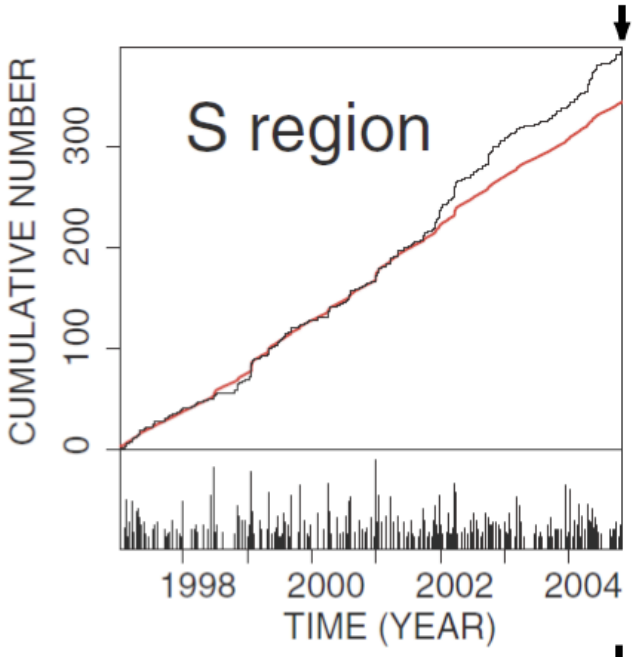

No-change
Change
0
100
200
300
400
500
1997
1999
2001
2003
ORDINARY TIME (DAYS)

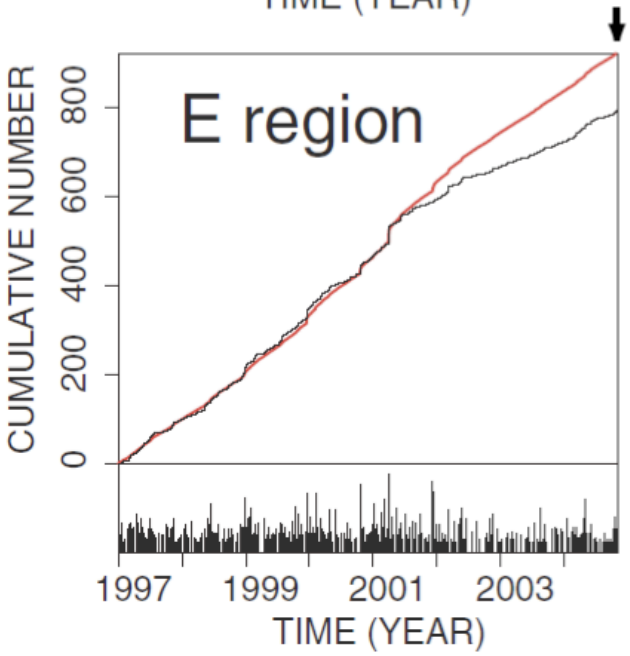

1997/01/01 - 2004/10/30 Number of events = 4060
Depth =< 25.0 km, M >= 2.0
137
138
139
140
9
8
7
6
N
W
S
E

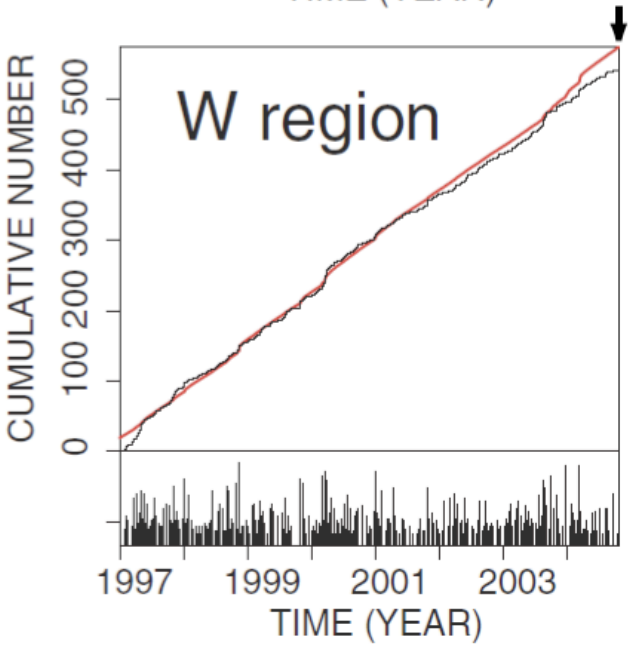

No-change
Change
0
200
400
600
1997
1999
2001
2003
ORDINARY TIME (DAYS)

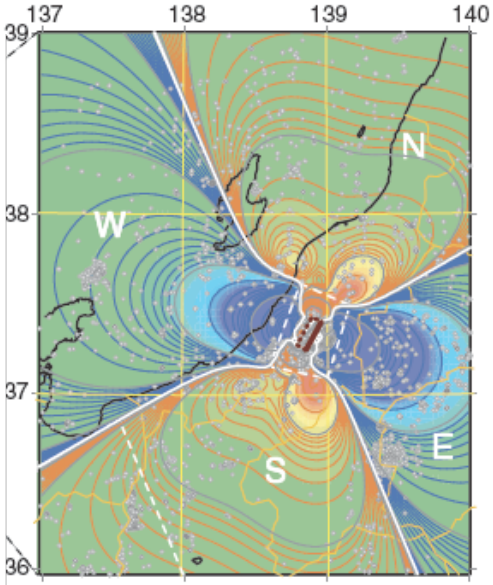

No-change
Change
CUMULATIVE NUMBER OF EVENTS
0
100
200
300
1998
2000
2002
2004

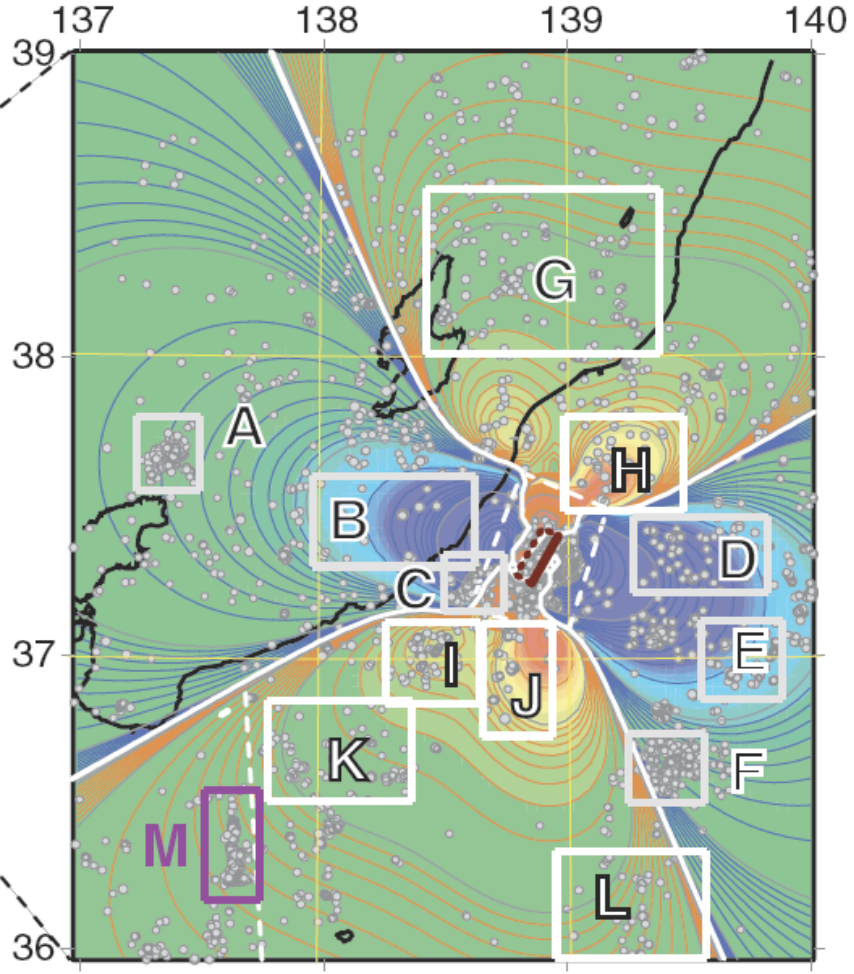

N region
CUMULATIVE NUMBER
0 100 200 300 400
1997 1999 2001 2003
TIME (YEAR)

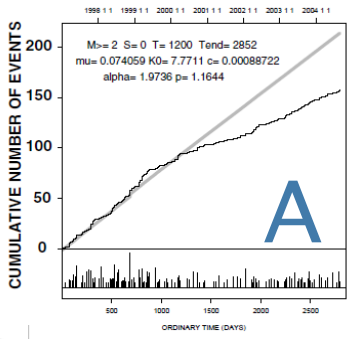

S region
CUMULATIVE NUMBER
0 100 200 300
1998 2000 2002 2004
TIME (YEAR)

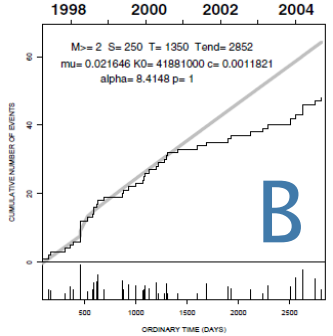

E region
CUMULATIVE NUMBER
0 200 400 600 800
1997 1999 2001 2003
TIME (YEAR)

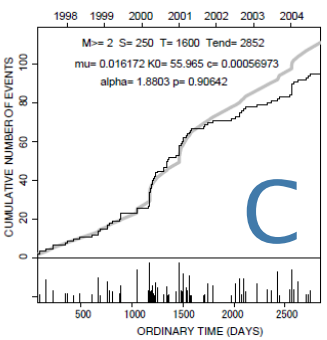

W region
CUMULATIVE NUMBER
0 100 200 300 400 500
1997 1999 2001 2003
TIME (YEAR)

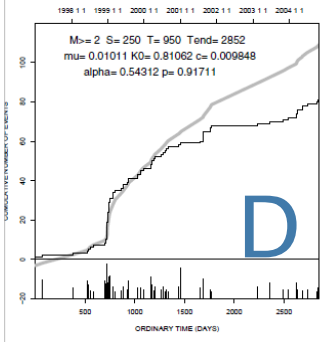

137
138
139
140
39
38
37
36
N
W
S
E

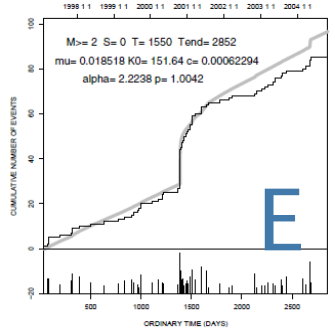

137
138
139
140
39
38
37
36
A
B
C
D
E
F
G
H
I
J
K
L
M

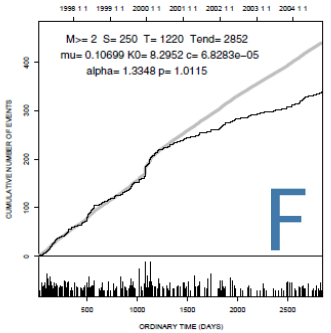

CUMULATIVE NUMBER OF EVENTS
M>= 2 S= 0 T= 1200 Tend= 2852
mu= 0.074059 K0= 7.7711 c= 0.00088722
alpha= 1.9736 p= 1.1644
A

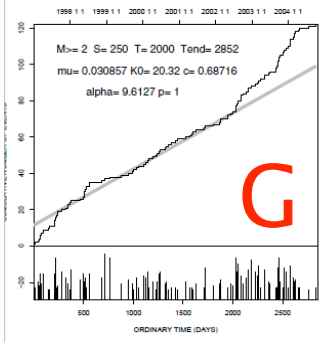

1998 2000 2002 2004
M>= 2 S= 250 T= 1350 Tend= 2852
mu= 0.021646 K0= 41881000 c= 0.0011821
alpha= 8.4148 p= 1
B

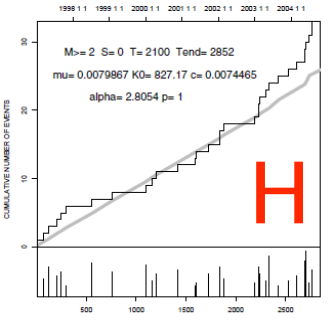

1998 1999 2000 2001 2002 2003 2004
M>= 2 S= 250 T= 1600 Tend= 2852
mu= 0.016172 K0= 55.965 c= 0.00056973
alpha= 1.8803 p= 0.90642
C
ORDINARY TIME (DAYS)

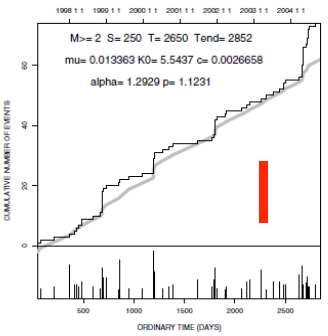

M>= 2 S= 250 T= 950 Tend= 2852
mu= 0.01011 K0= 0.81062 c= 0.009848
alpha= 0.54312 p= 0.91711
D

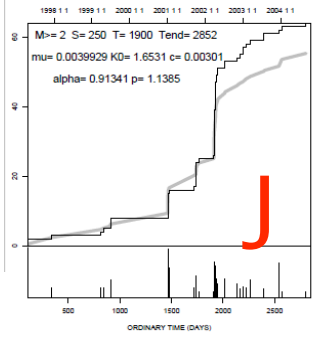

M>= 2 S= 0 T= 1550 Tend= 2852
mu= 0.018518 K0= 151.64 c= 0.00062294
alpha= 2.2238 p= 1.0042
E

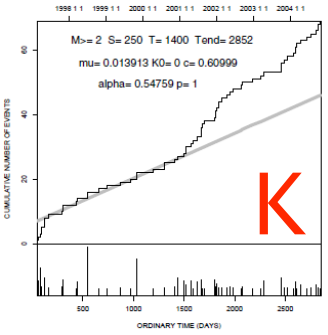

M>= 2 S= 250 T= 1220 Tend= 2852
mu= 0.10699 K0= 8.2952 c= 6.8283e-05
alpha= 1.3348 p= 1.0115
F

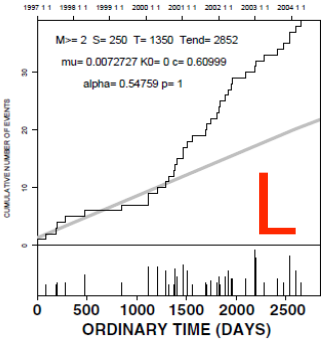

M>= 2 S= 250 T= 2000 Tend= 2852
mu= 0.030857 K0= 20.32 c= 0.68716
alpha= 9.6127 p= 1
G

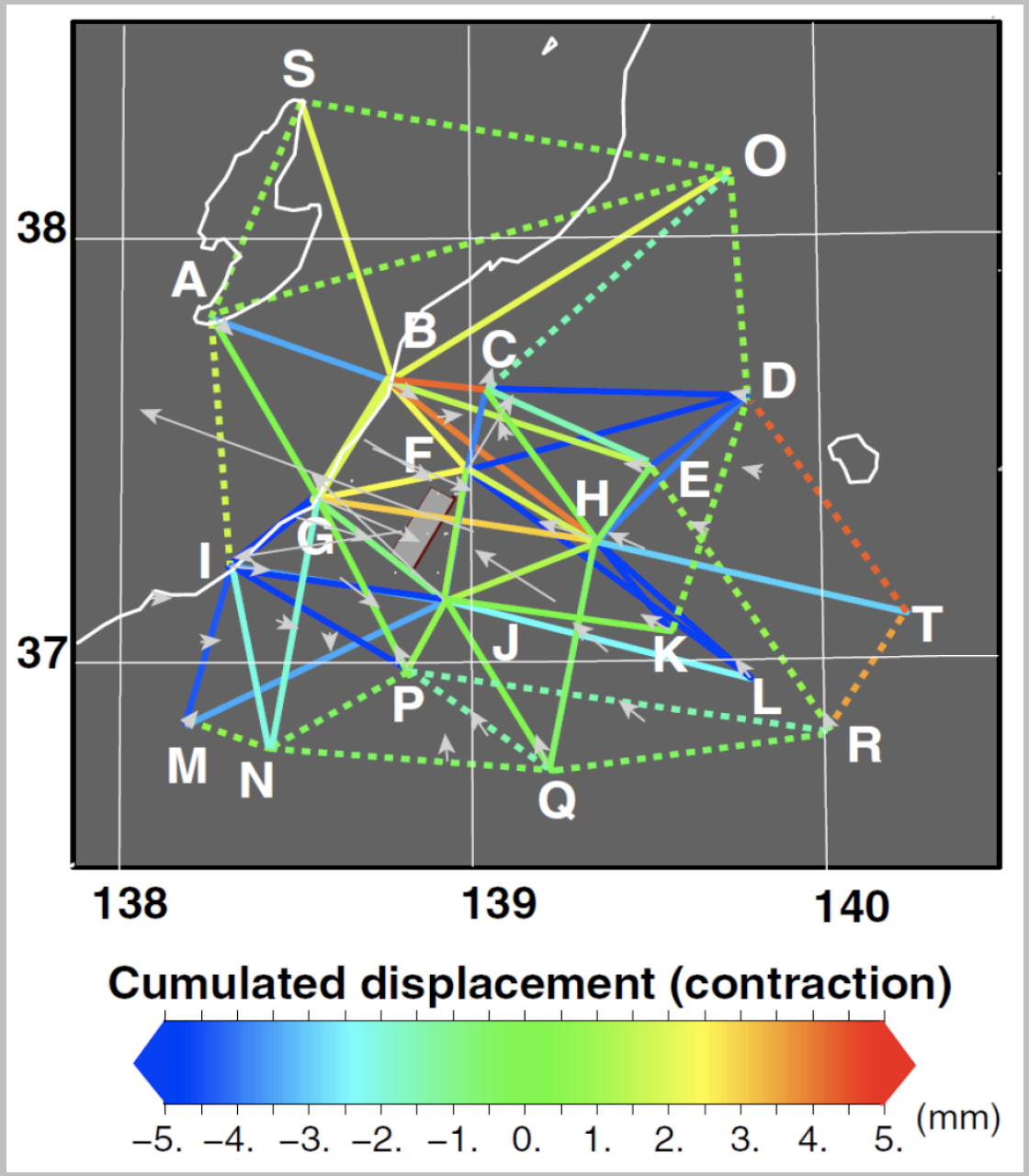

M>= 2 S= 0 T= 2100 Tend= 2852
mu= 0.0079867 K0= 827.17 c= 0.0074465
alpha= 2.8054 p= 1
H

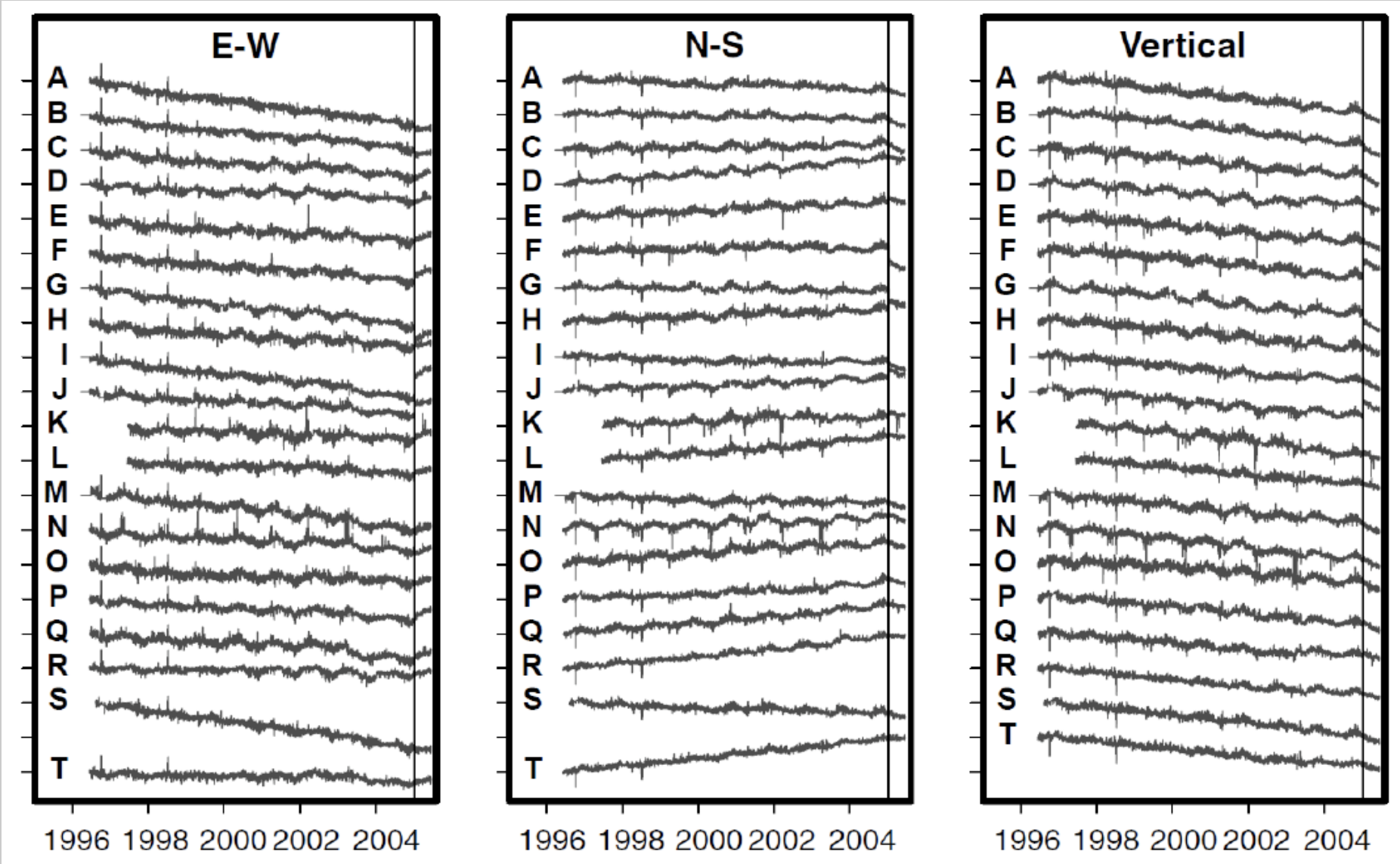

M>= 2 S= 250 T= 2650 Tend= 2852
mu= 0.013363 K0= 5.5437 c= 0.0026658
alpha= 1.2929 p= 1.1231
I

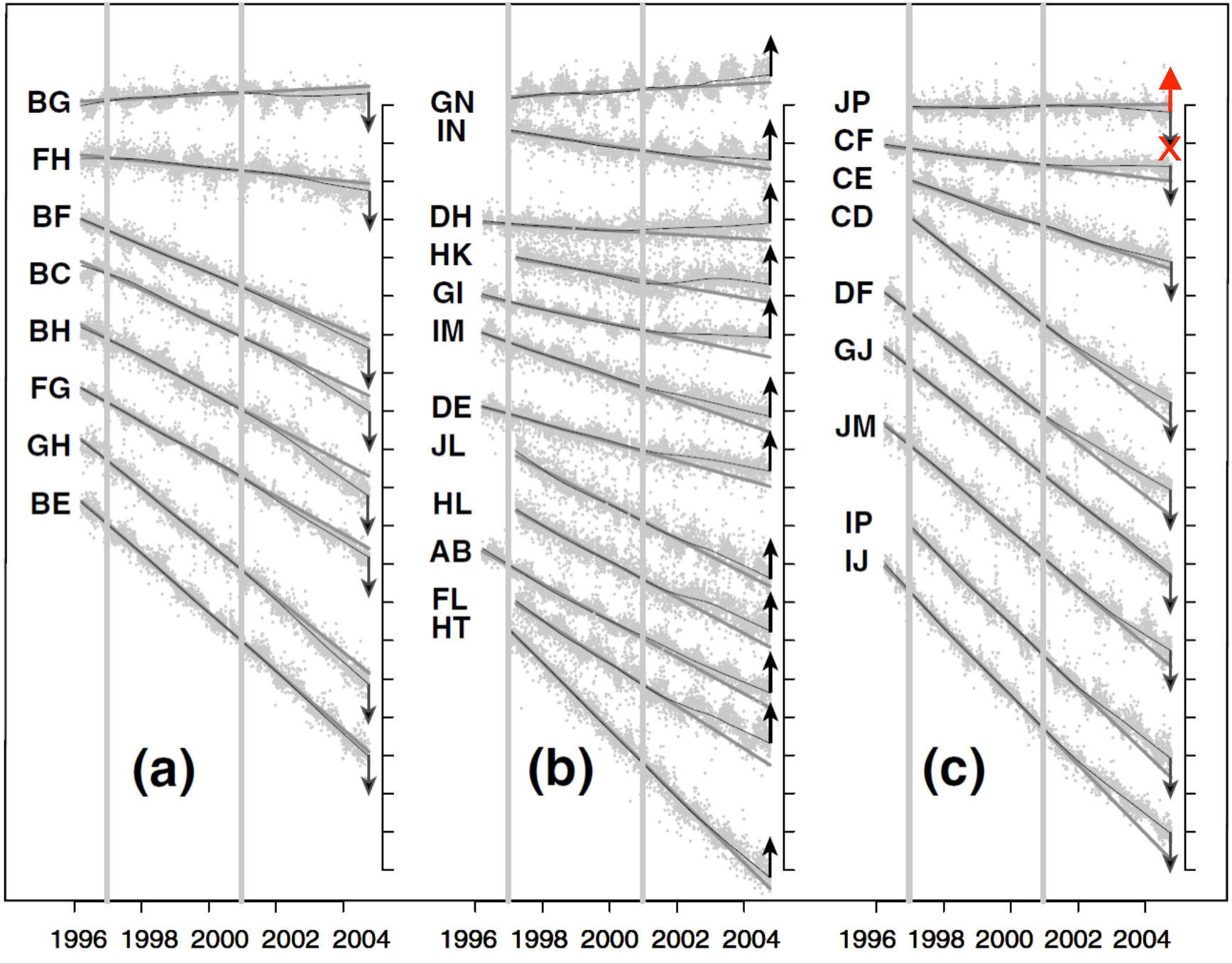

M>= 2 S= 250 T= 1900 Tend= 2852
mu= 0.0039929 K0= 1.6531 c= 0.00301
alpha= 0.91341 p= 1.1385
J

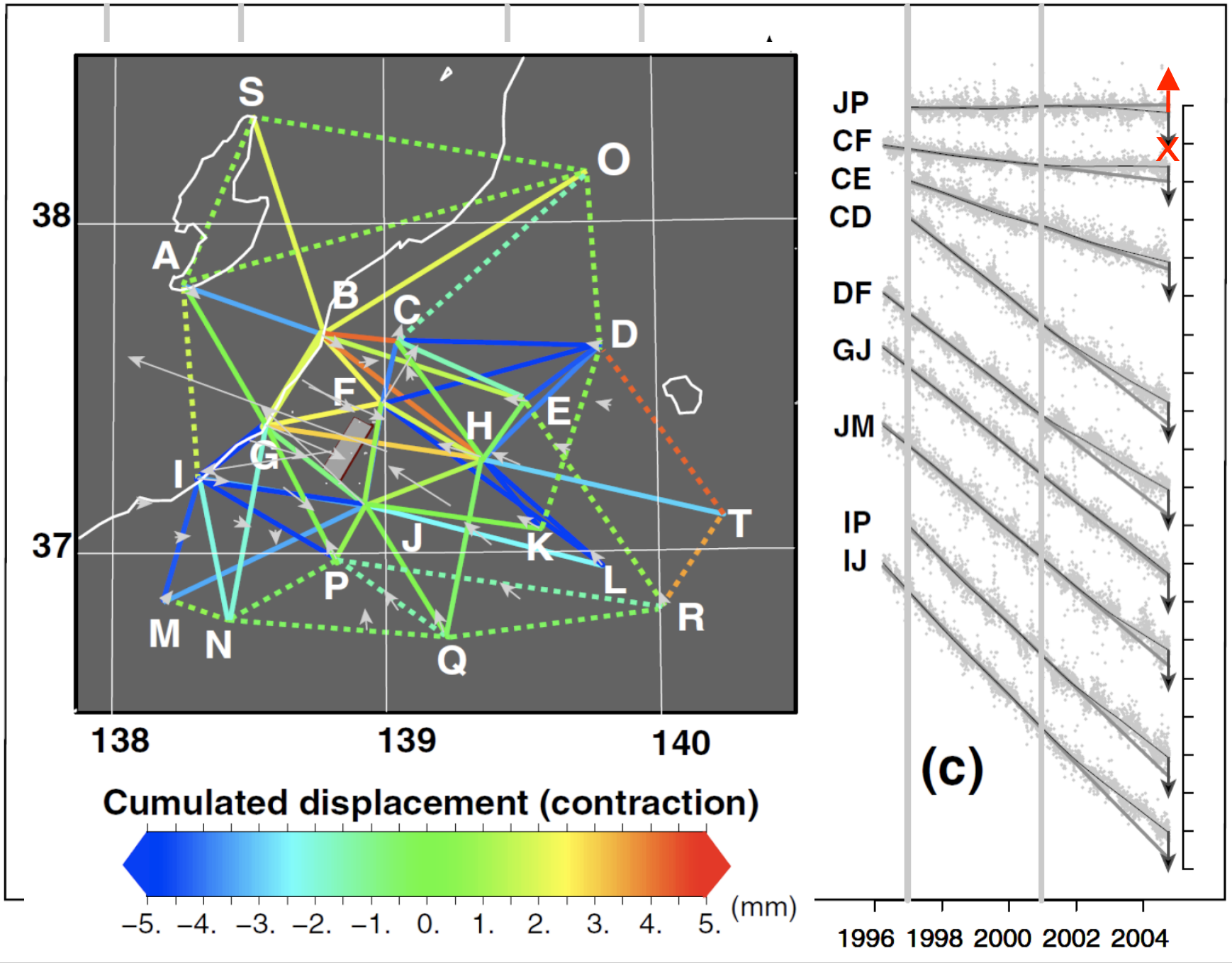

M>= 2 S= 250 T= 1400 Tend= 2852
mu= 0.013913 K0= 0 c= 0.60999
alpha= 0.54759 p= 1
K

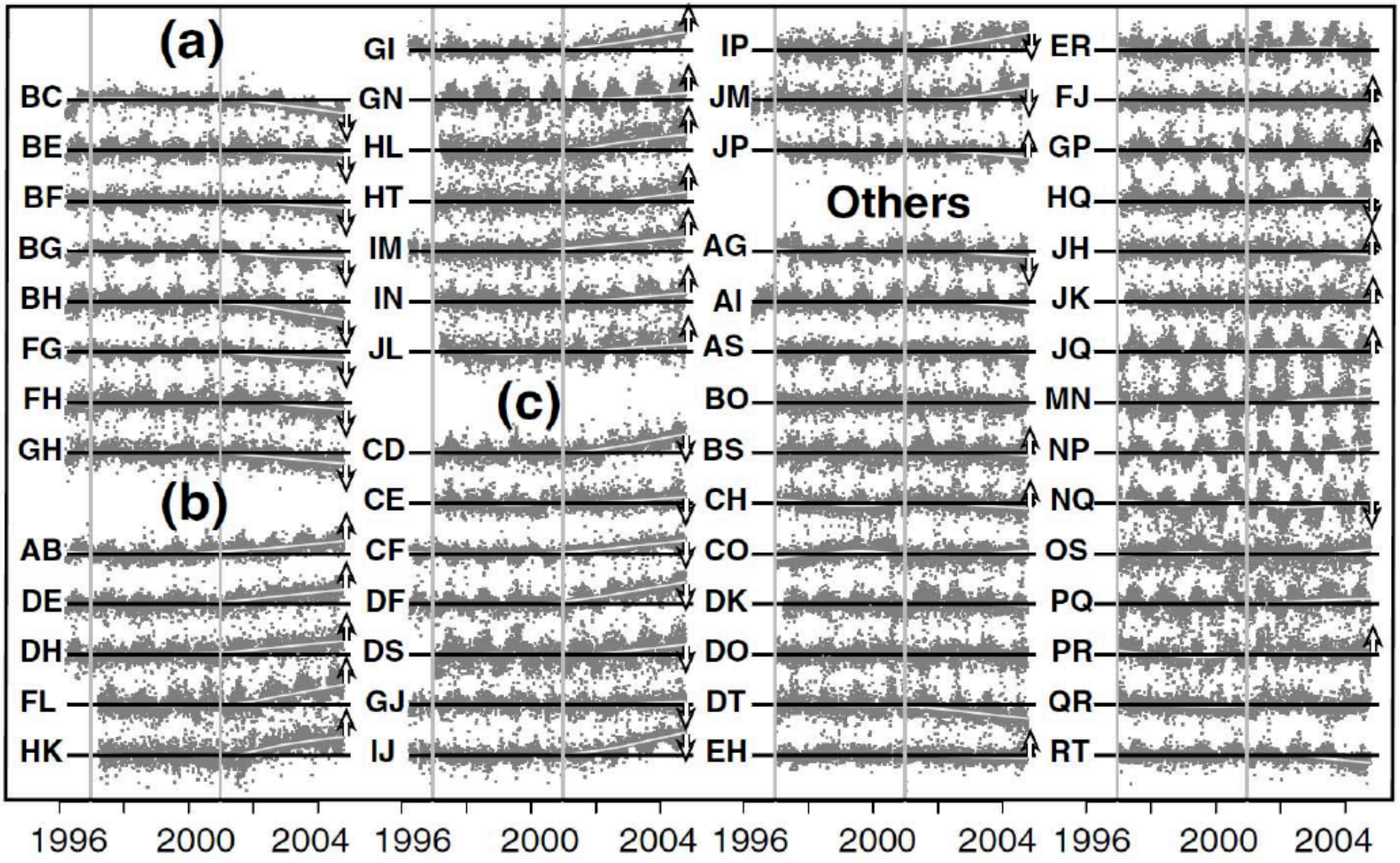

M>= 2 S= 250 T= 1350 Tend= 2852
mu= 0.0072727 K0= 0 c= 0.60999
alpha= 0.54759 p= 1
L
0 500 1000 1500 2000 2500
ORDINARY TIME (DAYS)

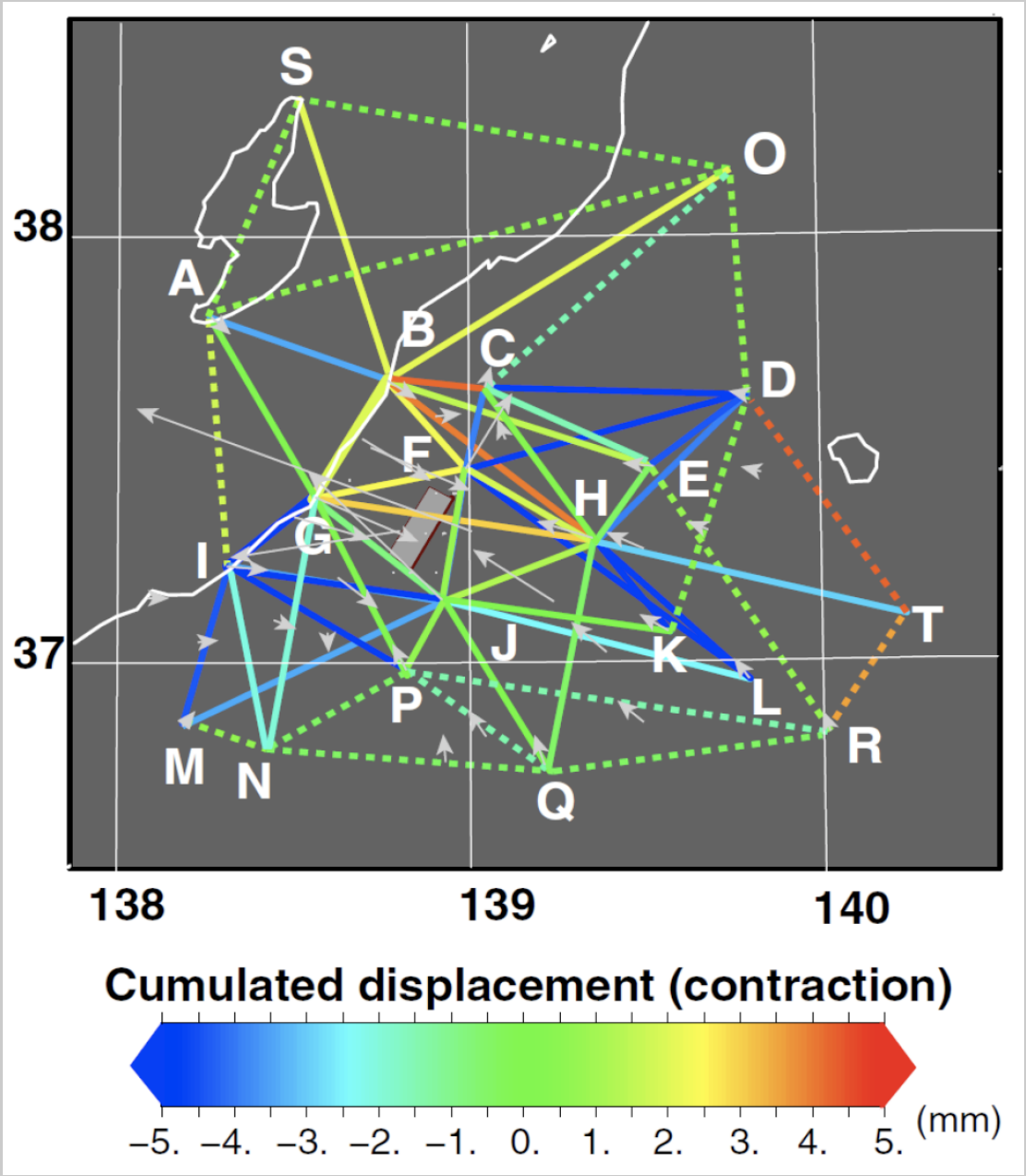

S
O
38
A
B
C
D
F
E
H
G
I
T
37
J
K
L
P
M
N
Q
R
138
139
140
Cumulated displacement (contraction)
−5. −4. −3. −2. −1. 0. 1. 2. 3. 4. 5.
(mm)


E-W
N-S
Vertical
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
1996 1998 2000 2002 2004

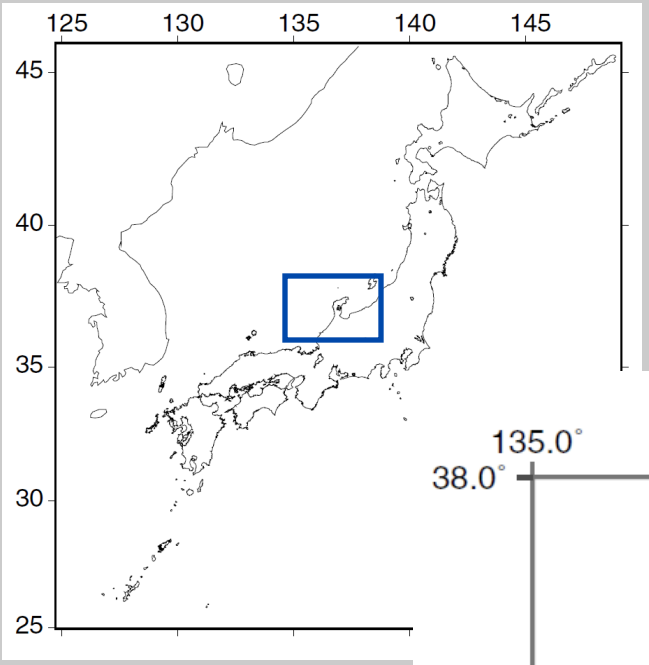

BG
FH
BF
BC
BH
FG
GH
BE
(a)
GN
IN
DH
HK
GI
IM
DE
JL
HL
AB
FL
HT
(b)
JP
CF
CE
CD
DF
GJ
JM
IP
IJ
(c)
1996 1998 2000 2002 2004
1996 1998 2000 2002 2004
1996 1998 2000 2002 2004

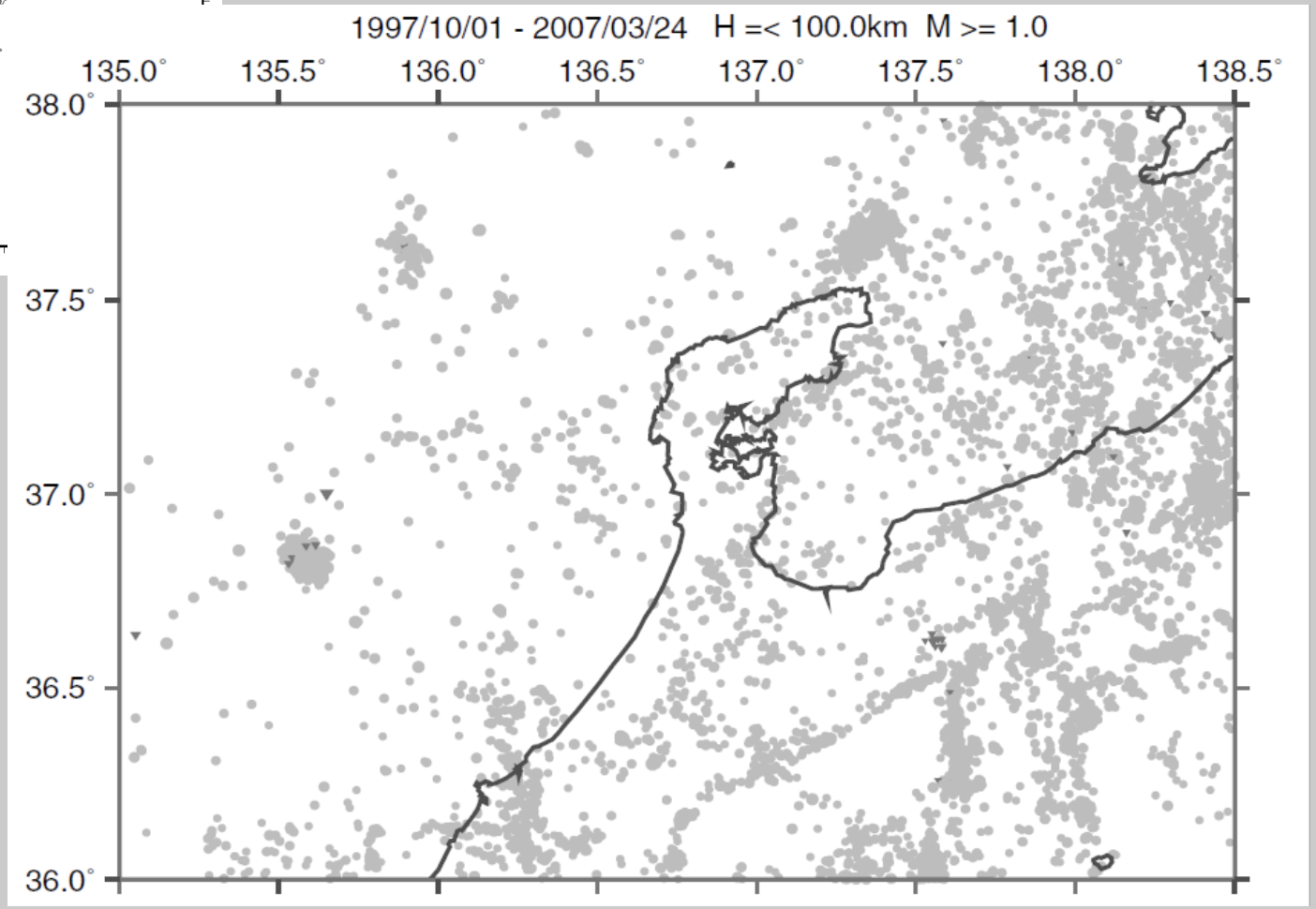

S
O
A
B
C
D
F
E
H
G
I
T
J
K
L
P
M
N
Q
R
38
37
138
139
140
Cumulated displacement (contraction)
−5. −4. −3. −2. −1. 0. 1. 2. 3. 4. 5.
(mm)
JP
CF
CE
CD
DF
GJ
JM
IP
IJ
X
(c)
1996 1998 2000 2002 2004

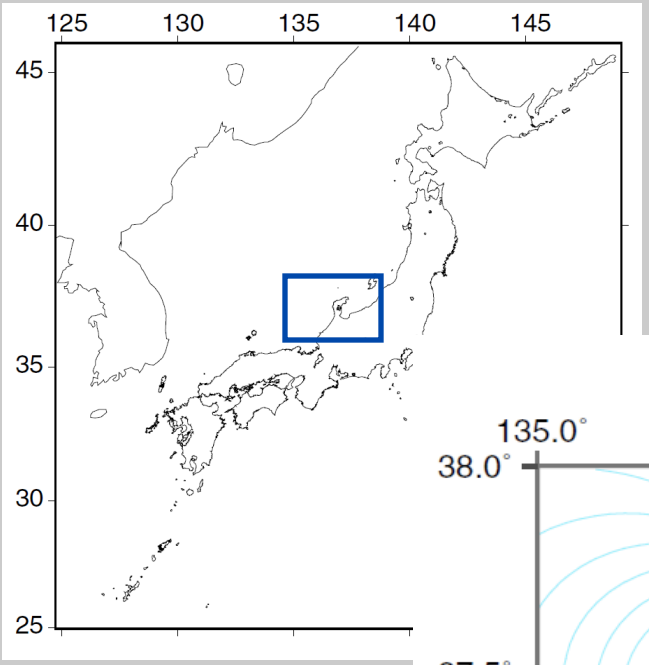

(a)
BC
BE
BF
BG
BH
FG
FH
GH
(b)
AB
DE
DH
FL
HK
GI
GN
HL
HT
IM
IN
JL
(c)
CD
CE
CF
DF
DS
GJ
IJ
IP
JM
JP
Others
AG
AI
AS
BO
BS
CH
CO
DK
DO
DT
EH
ER
FJ
GP
HQ
JH
JK
JQ
MN
NP
NQ
OS
PQ
PR
QR
RT
1996
2000
2004
1996
2000
2004
1996
2000
2004
1996
2000
2004

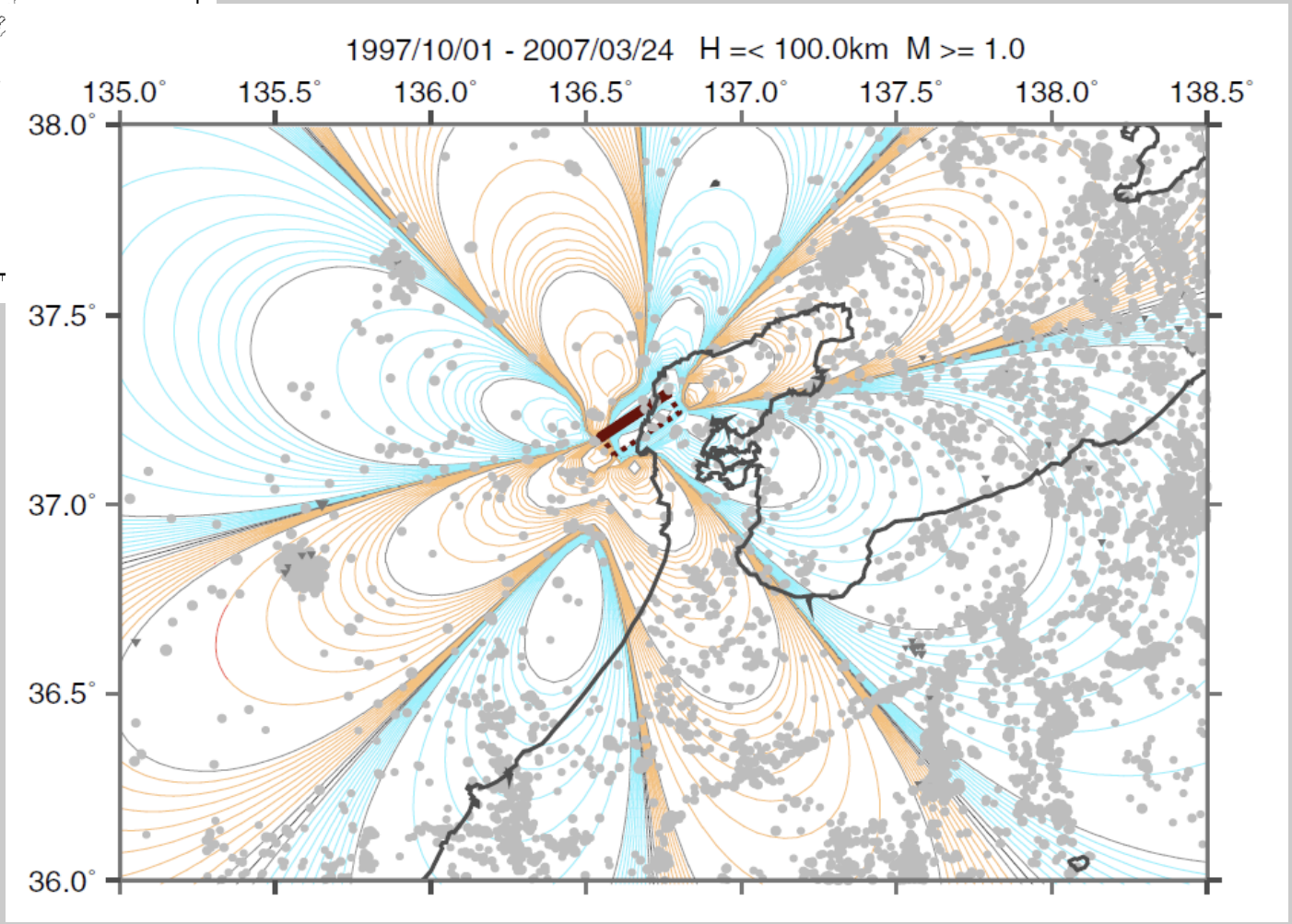

S
O
38
A
B
C
D
F
E
H
G
I
T
37
J
K
L
P
R
M
N
Q
138
139
140
Cumulated displacement (contraction)
−5. −4. −3. −2. −1. 0. 1. 2. 3. 4. 5.
(mm)

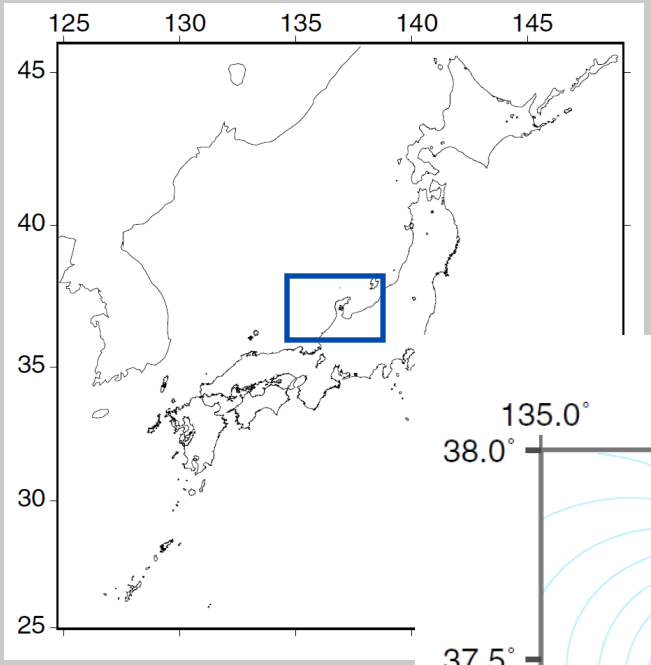
The March 2007 Noto Peninsula Earthquake

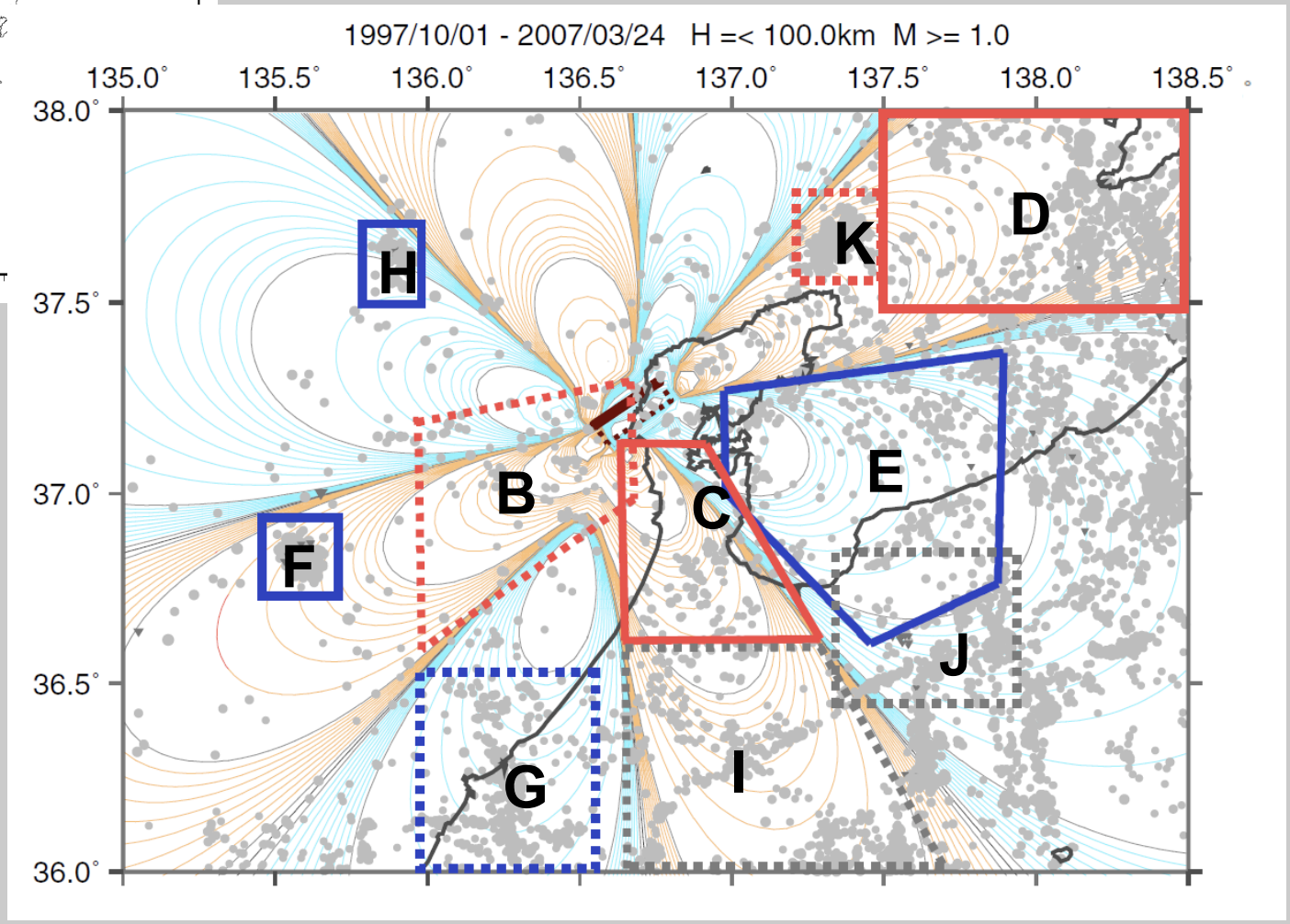

125
130
135
140
145
45
40
35
30
25

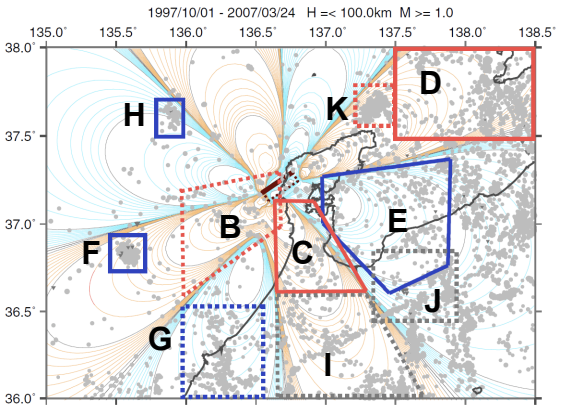

1997/10/01 - 2007/03/24 H =< 100.0km M >= 1.0
135.0°
135.5°
136.0°
136.5°
137.0°
137.5°
138.0°
138.5°
38.0°
37.5°
37.0°
36.5°
36.0°

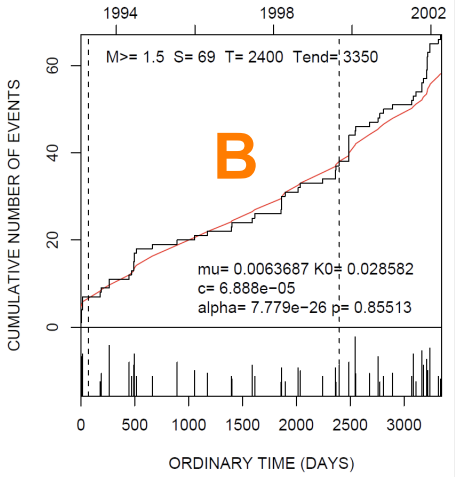

125
130
135
140
145
45
40
35
30
25

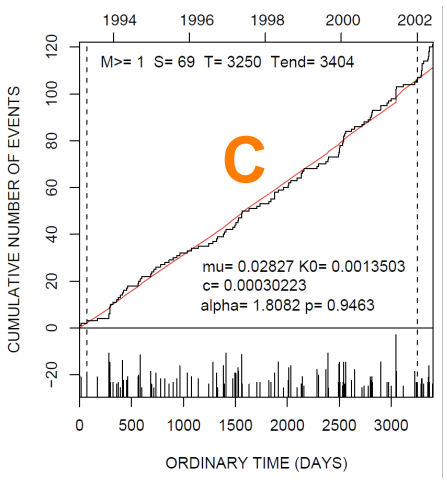

1997/10/01 - 2007/03/24 H =< 100.0km M >= 1.0
135.0°
135.5°
136.0°
136.5°
137.0°
137.5°
138.0°
138.5°
38.0°
37.5°
37.0°
36.5°
36.0°

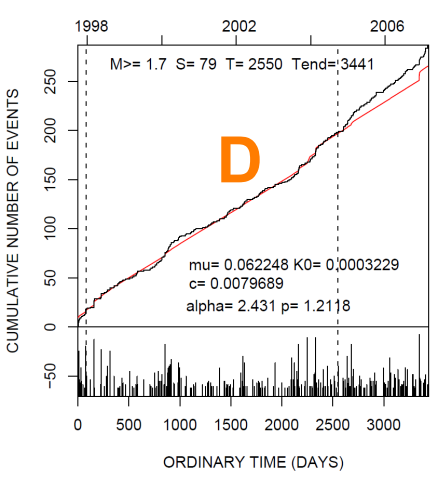

125
130
135
140
145
45
40
35
30
25

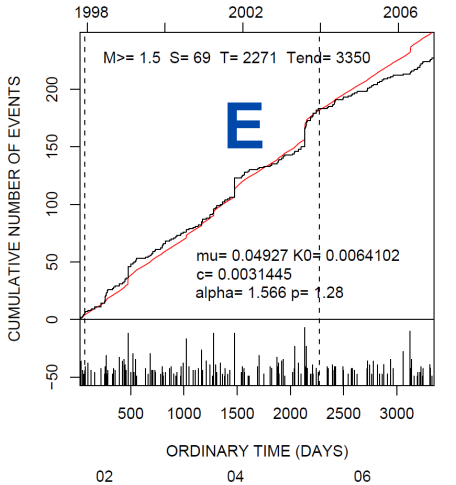

1997/10/01 - 2007/03/24 H =< 100.0km M >= 1.0
135.0°
135.5°
136.0°
136.5°
137.0°
137.5°
138.0°
138.5°
38.0°
37.5°
37.0°
36.5°
36.0°
H
K
D
B
C
E
F
J
G
I

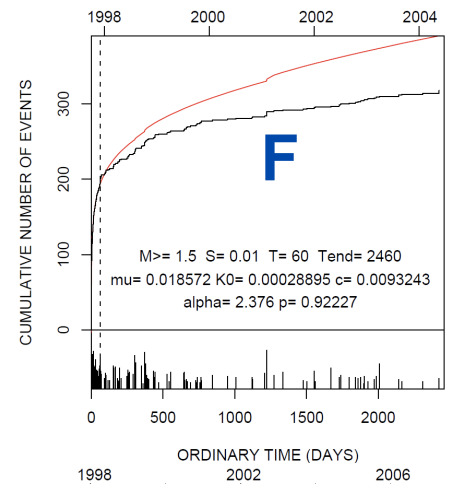

1997/10/01 - 2007/03/24 H =< 100.0km M >= 1.0
135.0° 135.5° 136.0° 136.5° 137.0° 137.5° 138.0° 138.5°
38.0° 37.5° 37.0° 36.5° 36.0°
H
K
D
B
C
E
F
J
G
I

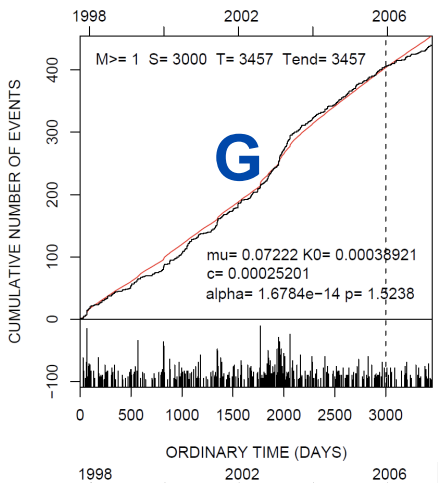

M>= 1.5 S= 69 T= 2400 Tend= 3350
B
mu= 0.0063687 K0= 0.028582
c= 6.888e−05
alpha= 7.779e−26 p= 0.85513
CUMULATIVE NUMBER OF EVENTS
ORDINARY TIME (DAYS)

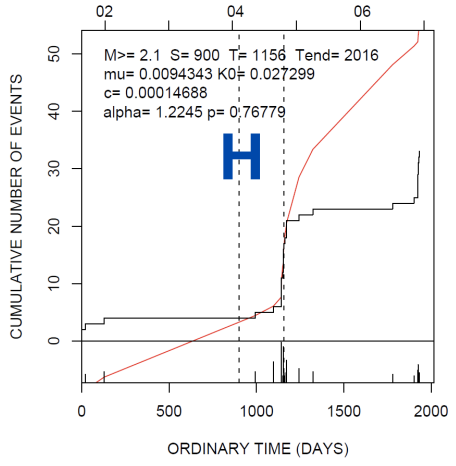

M>= 1 S= 69 T= 3250 Tend= 3404
C
mu= 0.02827 K0= 0.0013503
c= 0.00030223
alpha= 1.8082 p= 0.9463
CUMULATIVE NUMBER OF EVENTS
ORDINARY TIME (DAYS)

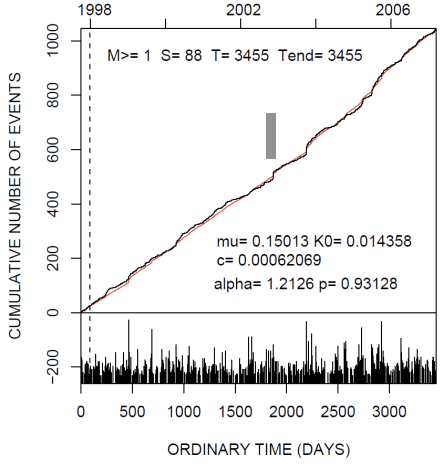

M>= 1.7 S= 79 T= 2550 Tend= 3441
D
mu= 0.062248 K0= 0.0003229
c= 0.0079689
alpha= 2.431 p= 1.2118
CUMULATIVE NUMBER OF EVENTS
ORDINARY TIME (DAYS)

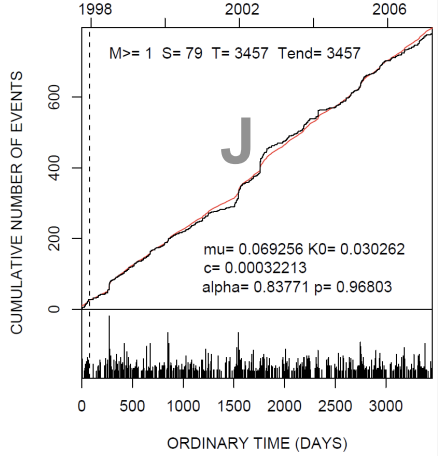

M>= 1.5 S= 69 T= 2271 Tend= 3350
E
mu= 0.04927 K0= 0.0064102
c= 0.0031445
alpha= 1.566 p= 1.28
CUMULATIVE NUMBER OF EVENTS
ORDINARY TIME (DAYS)

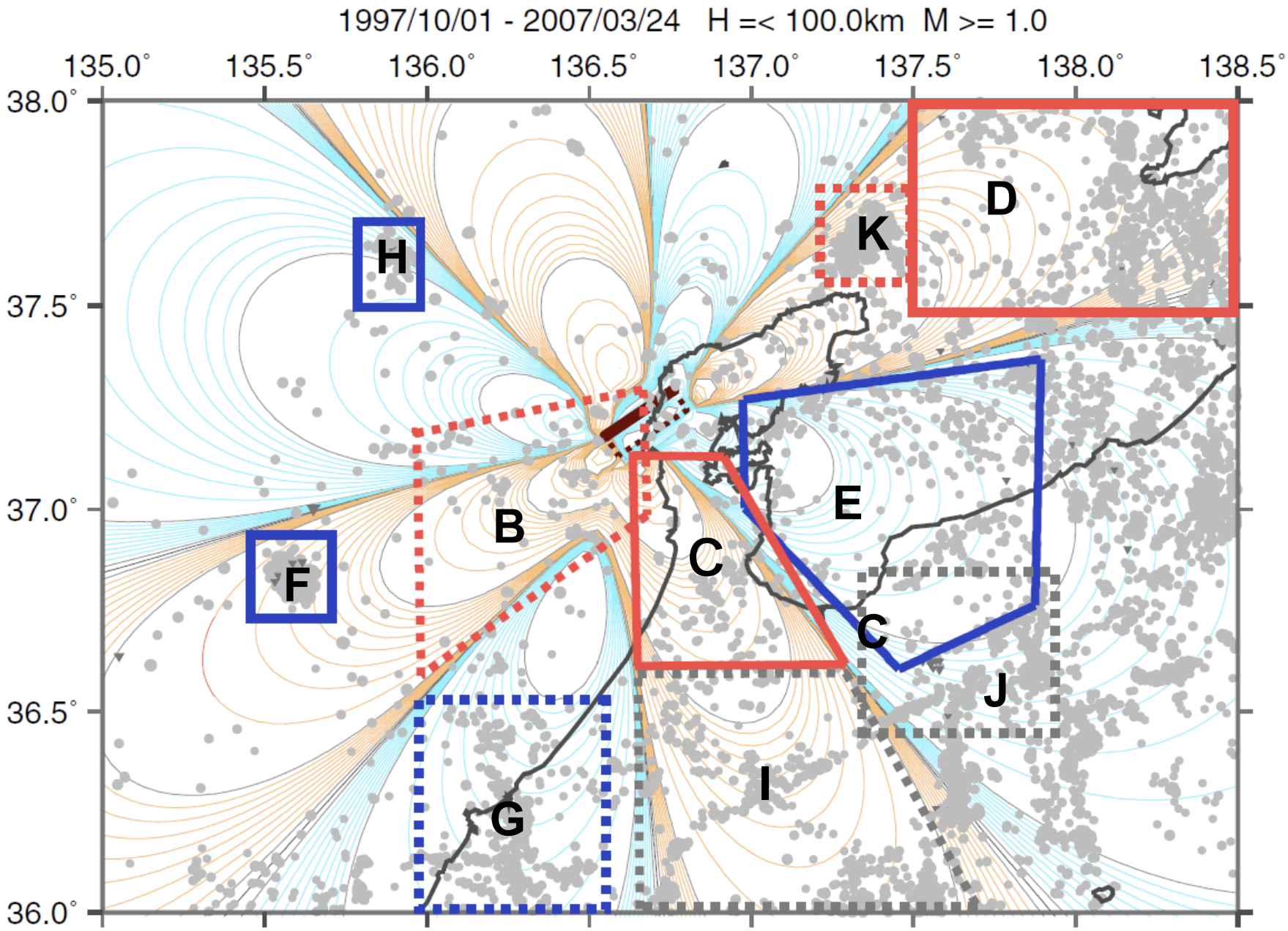

F
M>= 1.5 S= 0.01 T= 60 Tend= 2460
mu= 0.018572 K0= 0.00028895 c= 0.0093243
alpha= 2.376 p= 0.92227
CUMULATIVE NUMBER OF EVENTS
ORDINARY TIME (DAYS)

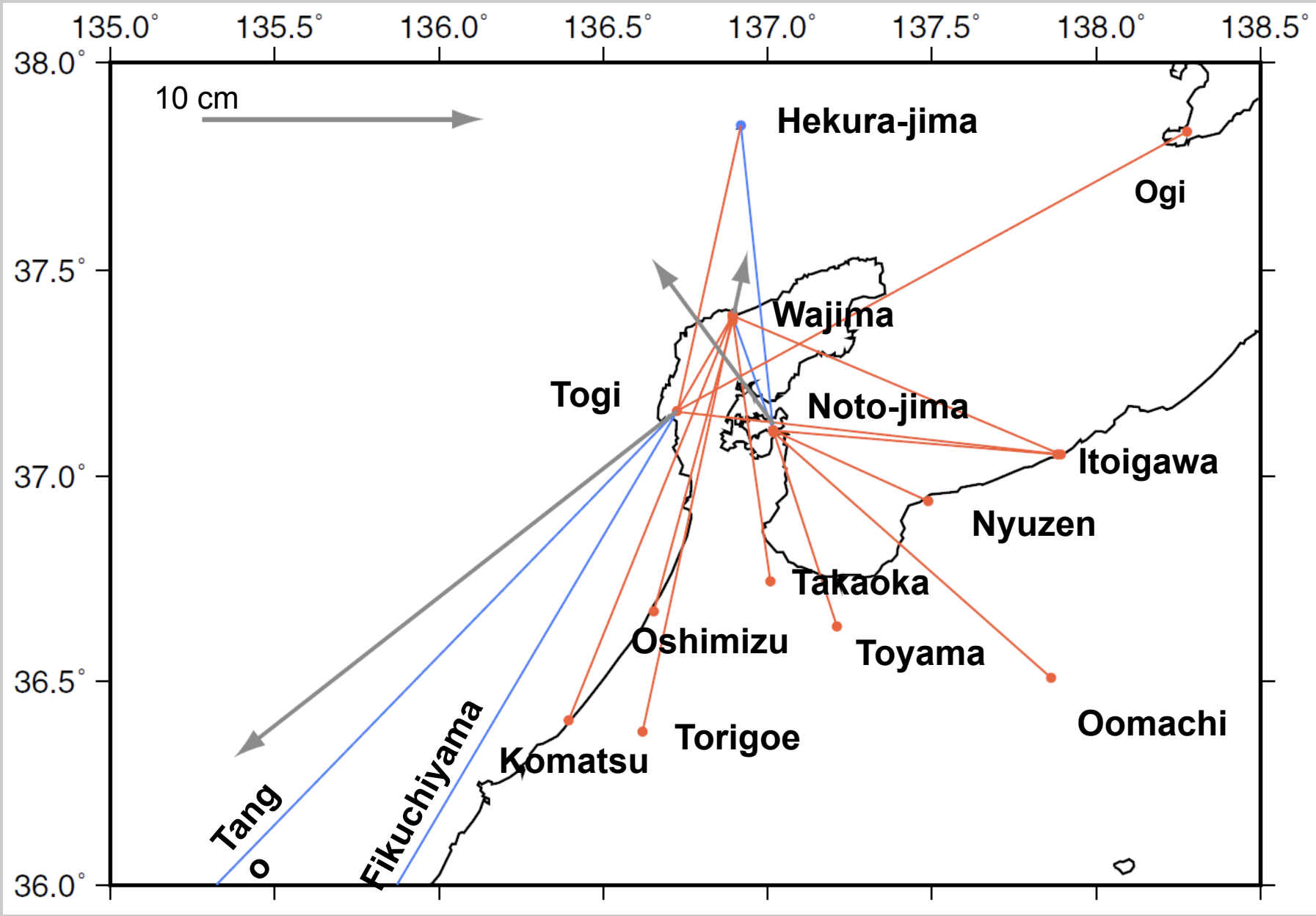

M>= 1 S= 3000 T= 3457 Tend= 3457
G
mu= 0.07222 K0= 0.00038921
c= 0.00025201
alpha= 1.6784e−14 p= 1.5238
CUMULATIVE NUMBER OF EVENTS
ORDINARY TIME (DAYS)

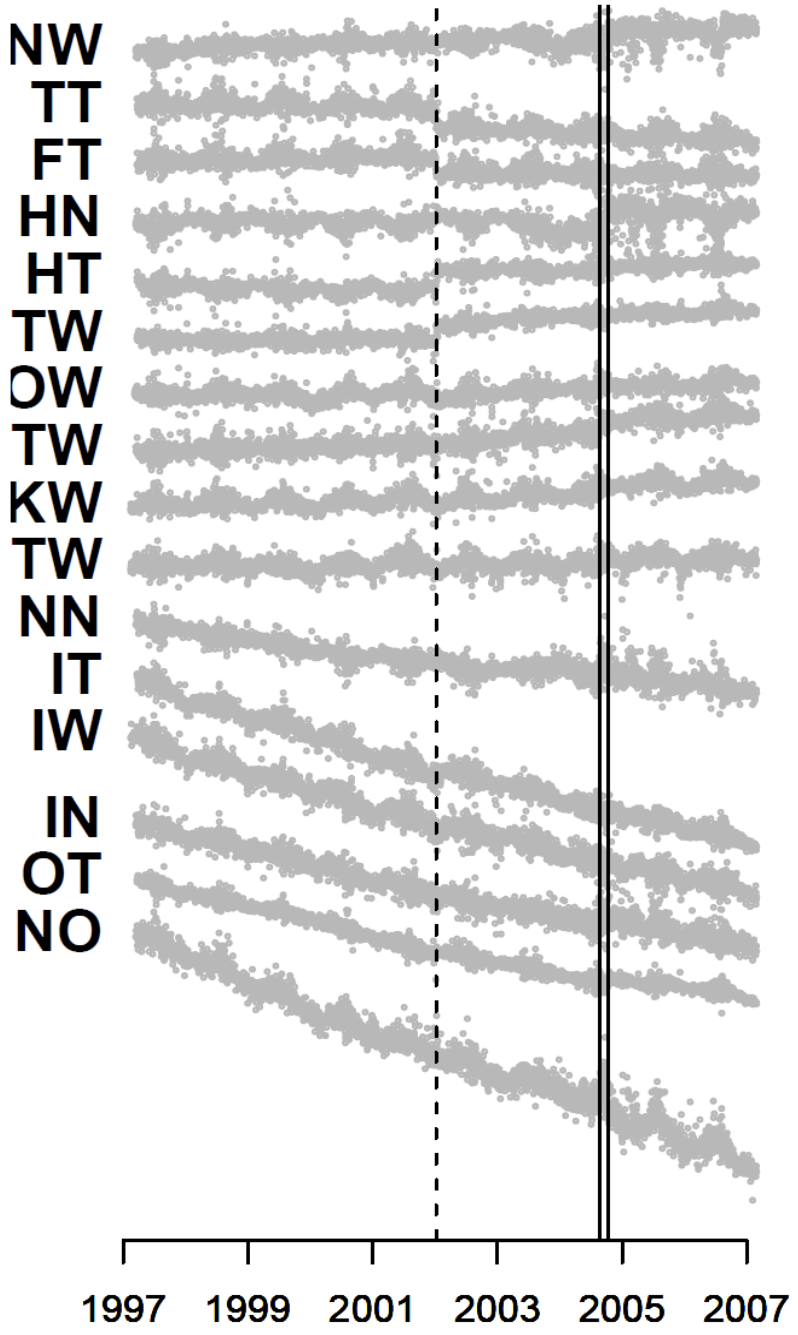

M>= 2.1 S= 900 T= 1156 Tend= 2016
mu= 0.0094343 K0= 0.027299
c= 0.00014688
alpha= 1.2245 p= 0.76779
H
CUMULATIVE NUMBER OF EVENTS
ORDINARY TIME (DAYS)

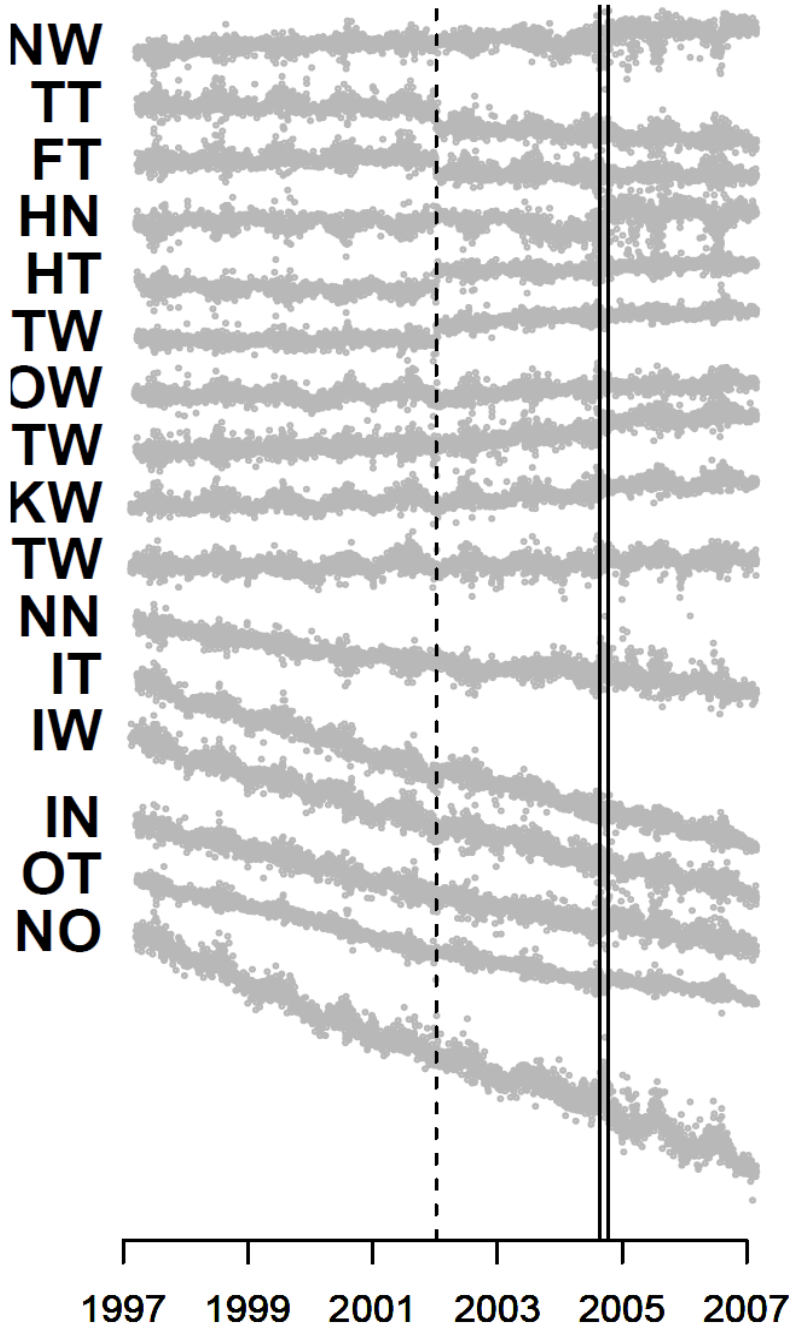

M>= 1 S= 88 T= 3455 Tend= 3455
I
mu= 0.15013 K0= 0.014358
c= 0.00062069
alpha= 1.2126 p= 0.93128
CUMULATIVE NUMBER OF EVENTS
ORDINARY TIME (DAYS)

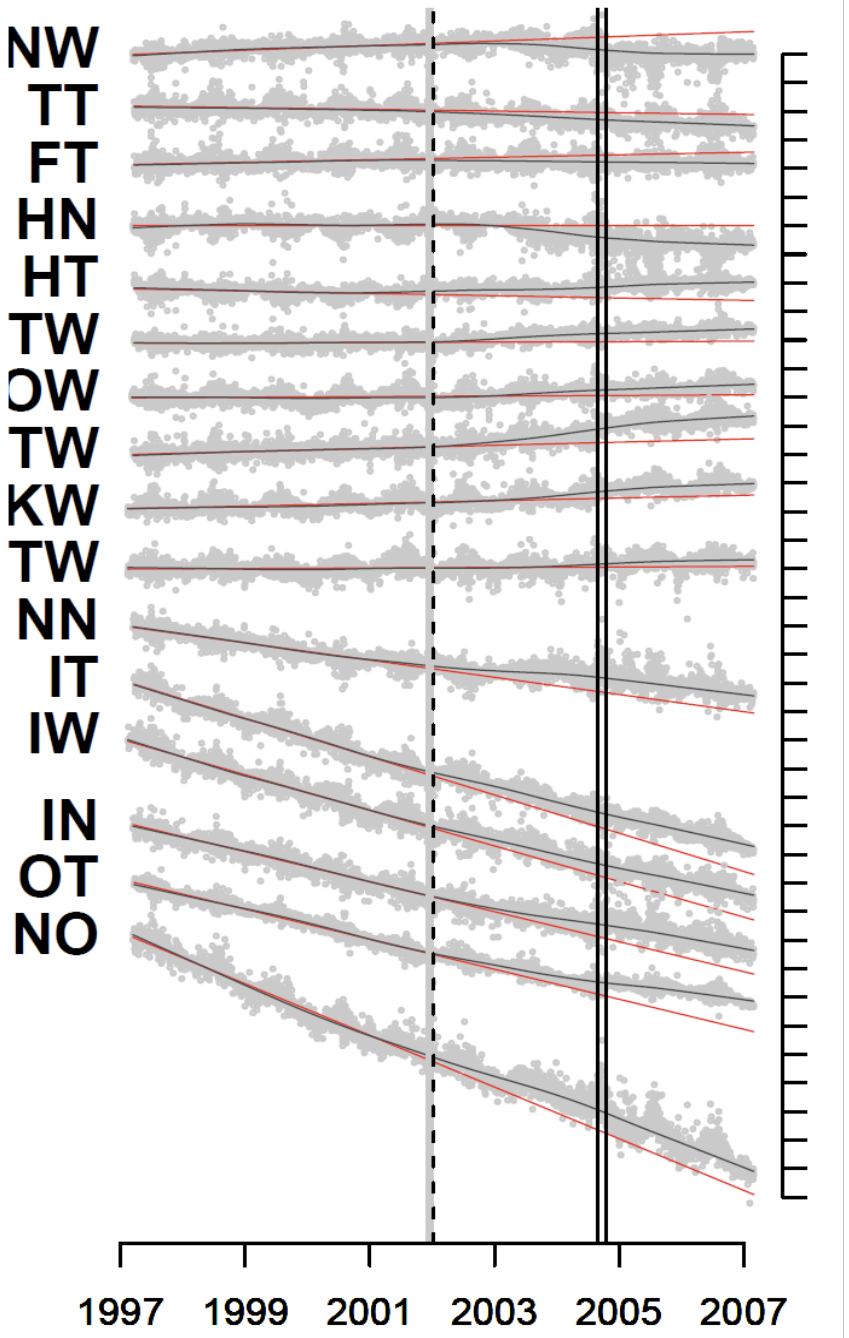

M>= 1 S= 79 T= 3457 Tend= 3457
J
mu= 0.069256 K0= 0.030262
c= 0.00032213
alpha= 0.83771 p= 0.96803
CUMULATIVE NUMBER OF EVENTS
ORDINARY TIME (DAYS)

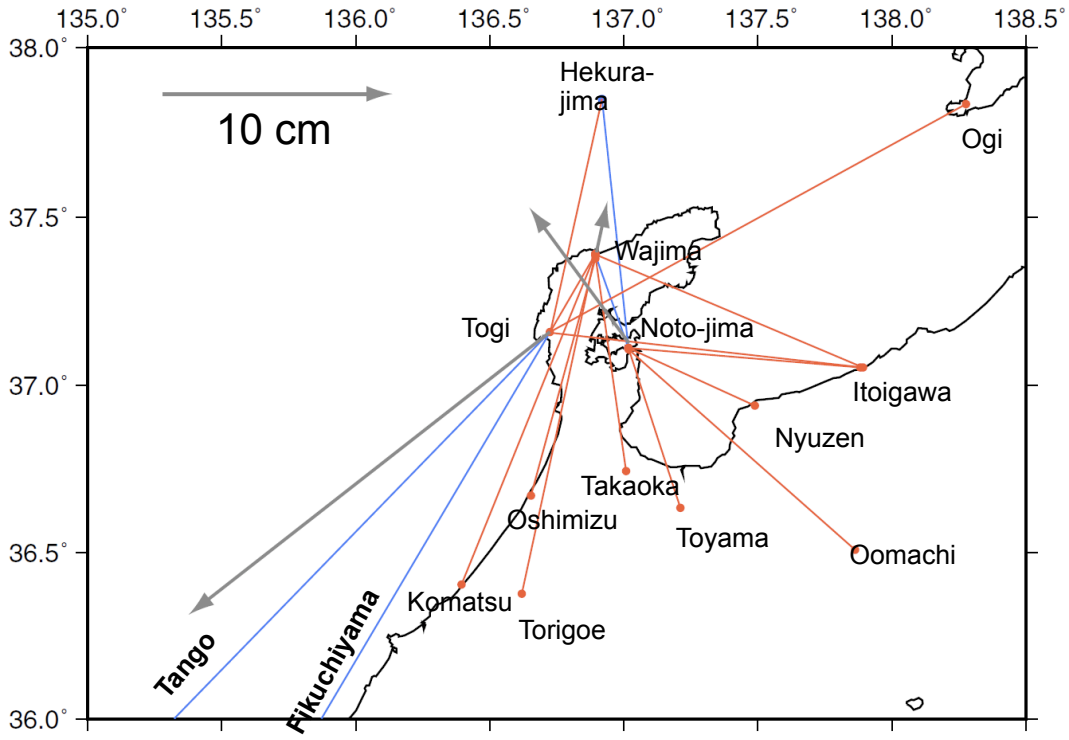

1997/10/01 - 2007/03/24 H =< 100.0km M >= 1.0
135.0°
135.5°
136.0°
136.5°
137.0°
137.5°
138.0°
138.5°
38.0°
37.5°
37.0°
36.5°
36.0°
H
K
D
F
B
C
E
C
J
G
I

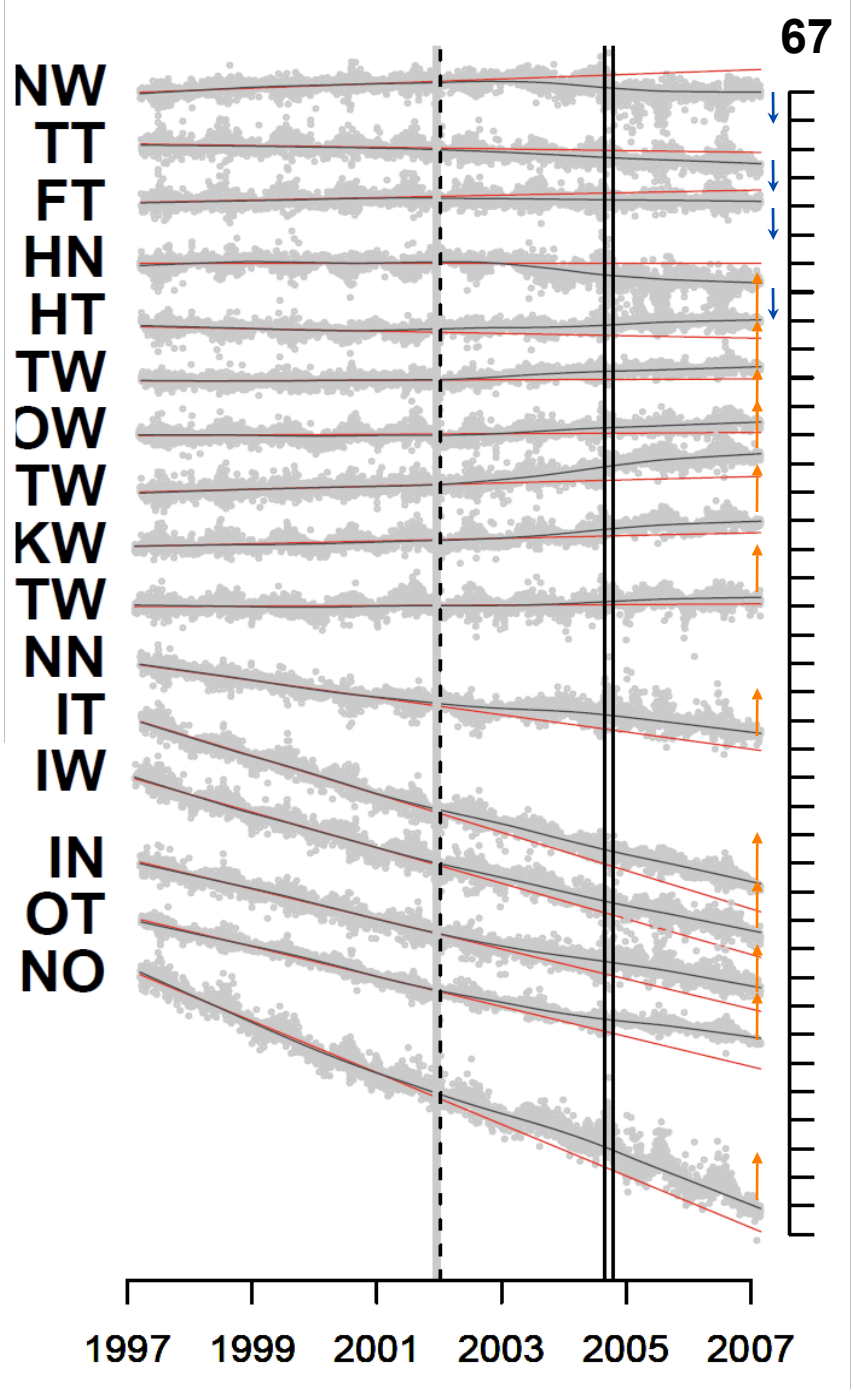

135.0°
135.5°
136.0°
136.5°
137.0°
137.5°
138.0°
138.5°
38.0°
37.5°
37.0°
36.5°
36.0°
10 cm
Hekura-jima
Ogi
Wajima
Togi
Noto-jima
Itoigawa
Nyuzen
Takaoka
Oshimizu
Toyama
Oomachi
Torigoe
Komatsu
Tang
o
Fikuchiyama


NW
TT
FT
HN
HT
TW
OW
TW
KW
TW
NN
IT
IW
IN
OT
NO
1997
1999
2001
2003
2005
2007

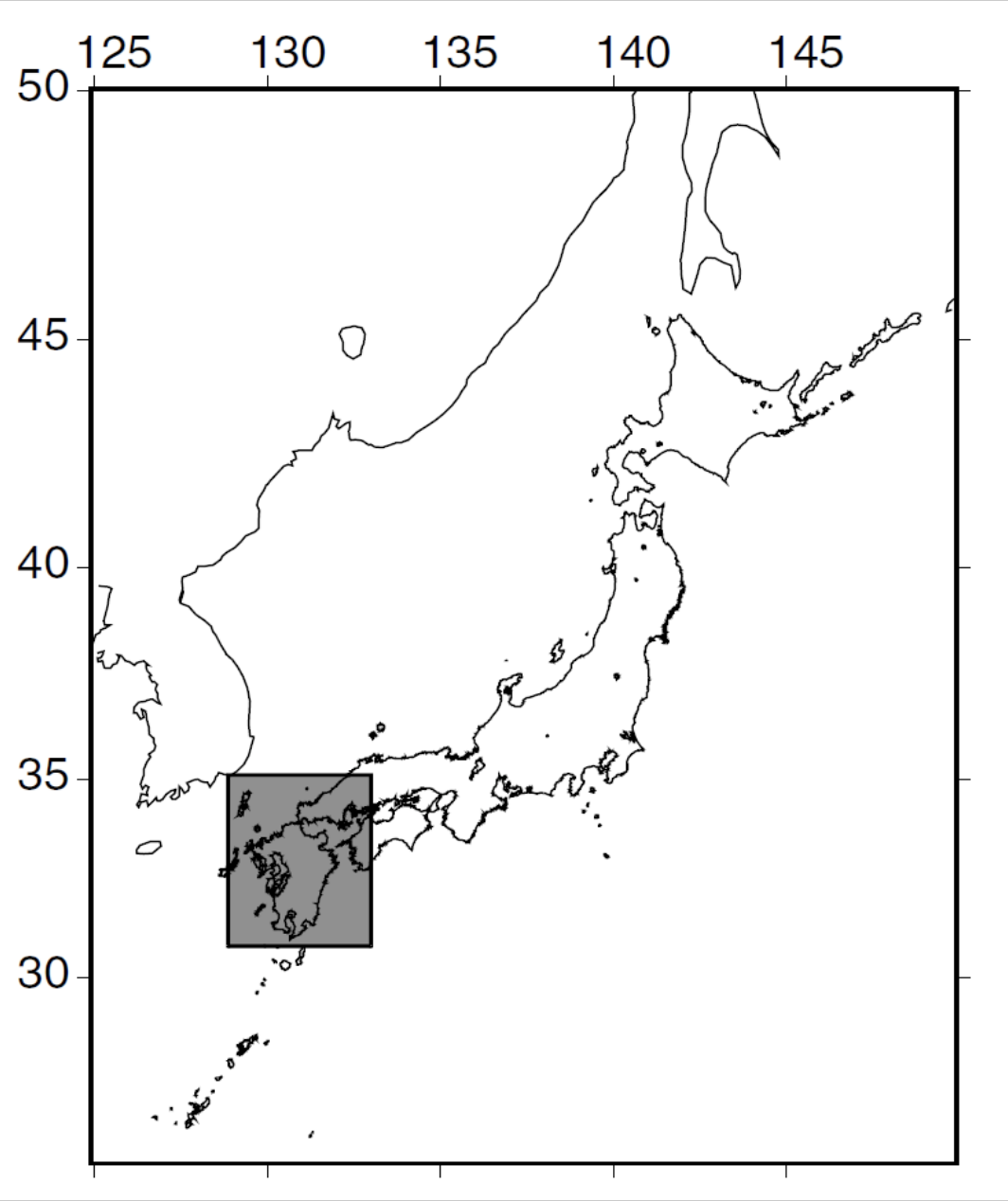

NW
TT
FT
HN
HT
TW
OW
TW
KW
TW
NN
IT
IW
IN
OT
NO
1997
1999
2001
2003
2005
2007

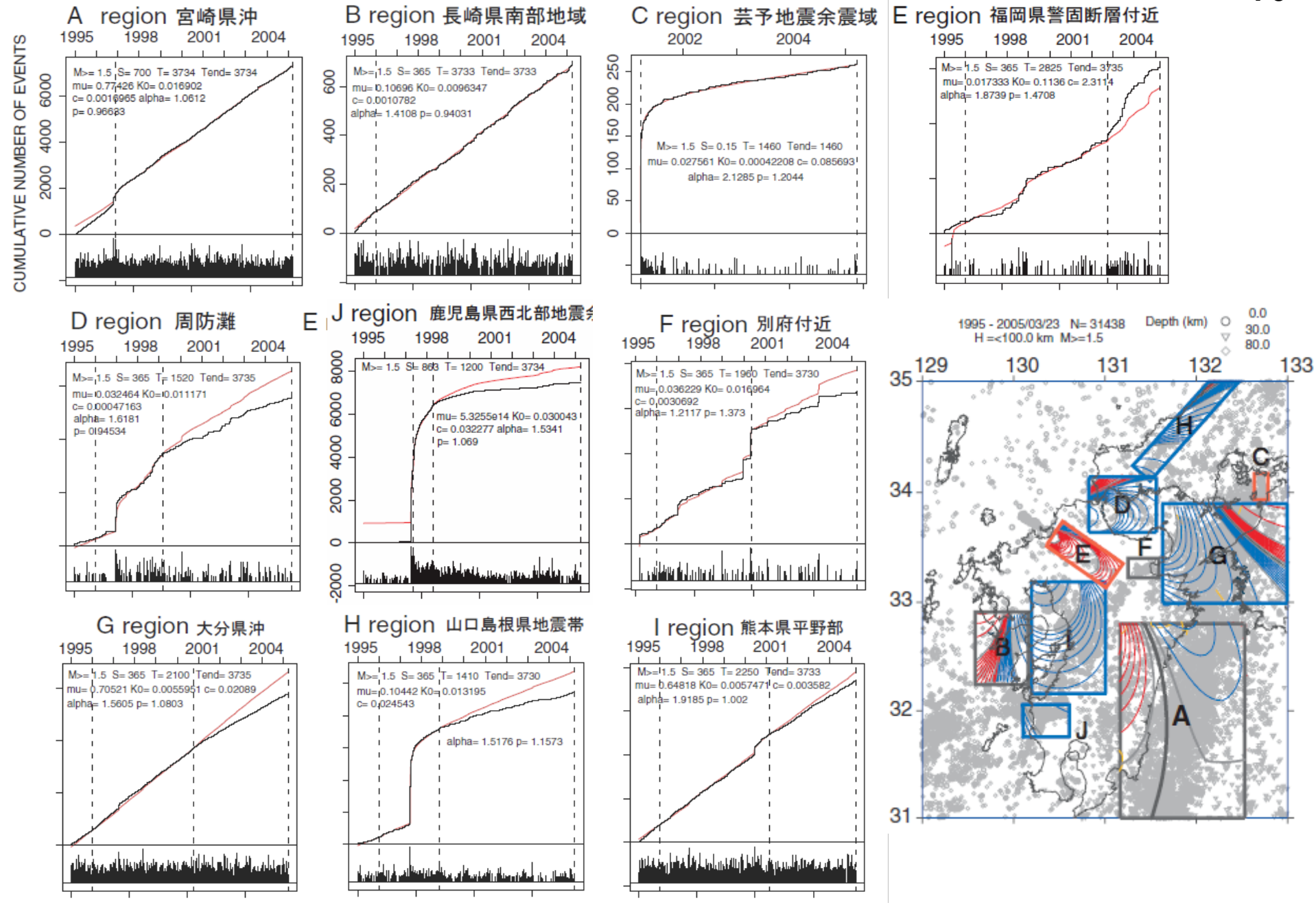

NW
TT
FT
HN
HT
TW
OW
TW
KW
TW
NN
IT
IW
IN
OT
NO
1997
1999
2001
2003
2005
2007

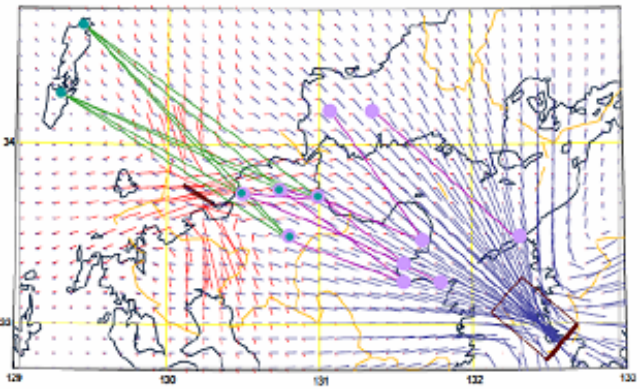

135.0°
135.5°
136.0°
136.5°
137.0°
137.5°
138.0°
138.5°
38.0°
37.5°
37.0°
36.5°
36.0°
10 cm
Hekura-
jima
Ogi
Wajima
Togi
Noto-jima
Itoigawa
Nyuzen
Takaoka
Oshimizu
Toyama
Oomachi
Komatsu
Torigoe
Tango
Fukuchiyama

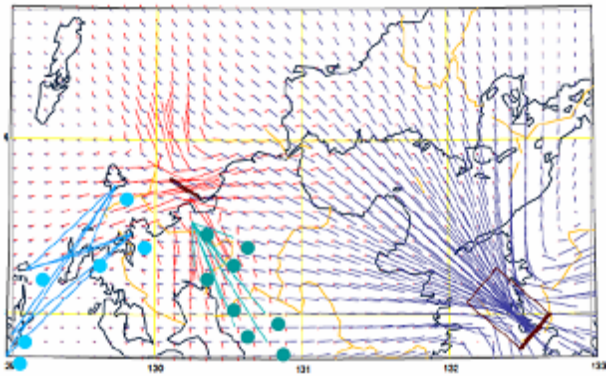

67
NW
TT
FT
HN
HT
TW
OW
TW
KW
TW
NN
IT
IW
IN
OT
NO
1997
1999
2001
2003
2005
2007

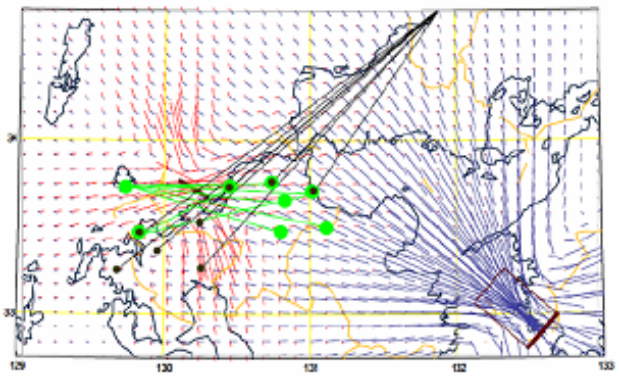
The 2005 Off coast of Western Fukuoka-Ken Earthquake

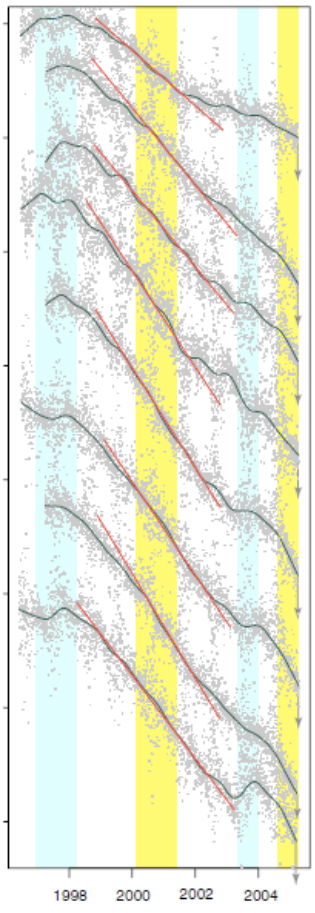

125
130
135
140
145
50
45
40
35
30

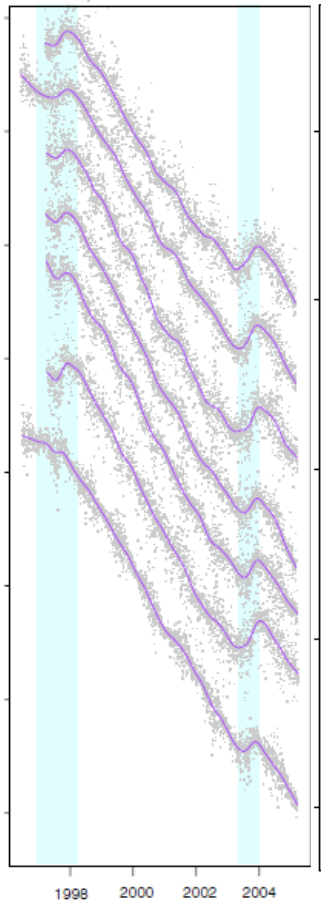

A region 宮崎県沖
B region 長崎県南部地域
C region 芸予地震余震域
E region 福岡県警固断層付近
D region 周防灘
J region 鹿児島県西北部地震
F region 別府付近
G region 大分県沖
H region 山口島根県地震帯
I region 熊本県平野部
CUMULATIVE NUMBER OF EVENTS
1995 1998 2001 2004
2002 2004
M>= 1.5 S= 700 T= 3734 Tend= 3734
mu= 0.77426 K0= 0.016902
c= 0.0016965 alpha= 1.0612
p= 0.96683
M>= 1.5 S= 365 T= 3733 Tend= 3733
mu= 0.10696 K0= 0.0096347
c= 0.0010782
alpha= 1.4108 p= 0.94031
M>= 1.5 S= 0.15 T= 1460 Tend= 1460
mu= 0.027561 K0= 0.00042208 c= 0.085693
alpha= 2.1285 p= 1.2044
M>= 1.5 S= 365 T= 2825 Tend= 3735
mu= 0.017333 K0= 0.1136 c= 2.3114
alpha= 1.8739 p= 1.4708
M>= 1.5 S= 365 T= 1520 Tend= 3735
mu= 0.032464 K0= 0.011171
c= 0.00047163
alpha= 1.6181
p= 0.94534
M>= 1.5 S= 863 T= 1200 Tend= 3734
mu= 5.3255e14 K0= 0.030043
c= 0.032277 alpha= 1.5341
p= 1.069
M>= 1.5 S= 365 T= 1960 Tend= 3730
mu= 0.036229 K0= 0.016964
c= 0.0030692
alpha= 1.2117 p= 1.373
M>= 1.5 S= 365 T= 2100 Tend= 3735
mu= 0.70521 K0= 0.0055951 c= 0.02089
alpha= 1.5605 p= 1.0803
M>= 1.5 S= 365 T= 1410 Tend= 3730
mu= 0.10442 K0= 0.013195
c= 0.024543
alpha= 1.5176 p= 1.1573
M>= 1.5 S= 365 T= 2250 Tend= 3733
mu= 0.64818 K0= 0.0057471 c= 0.003582
alpha= 1.9185 p= 1.002
1995 - 2005/03/23 N= 31438
H =<100.0 km M>=1.5
Depth (km)
0.0
30.0
80.0
129 130 131 132 133
35 34 33 32 31
A
B
C
D
E
F
G
H
I
J

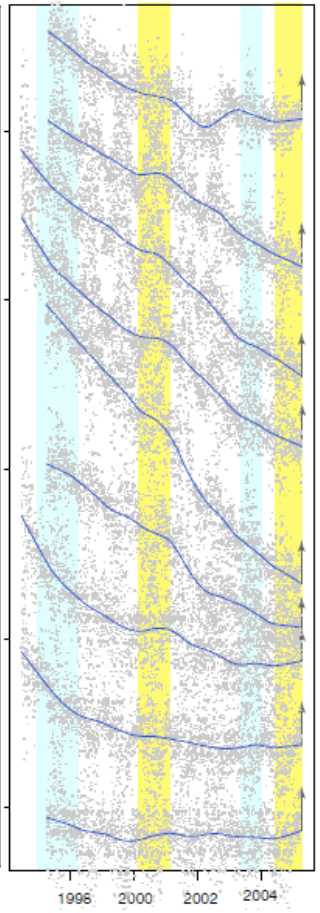


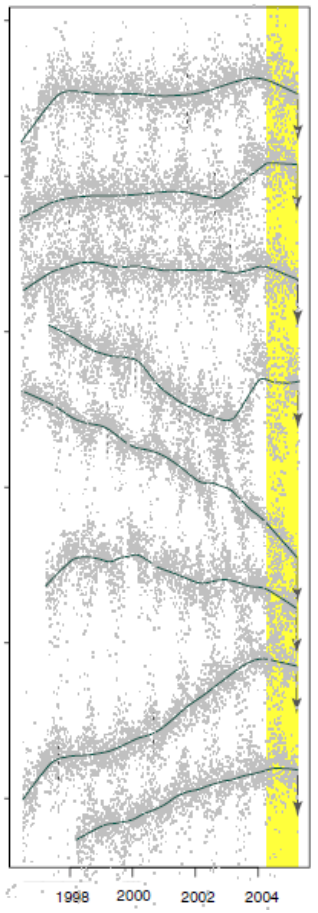


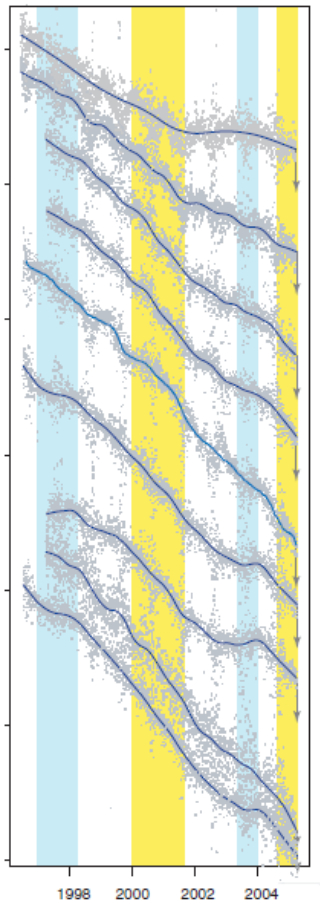


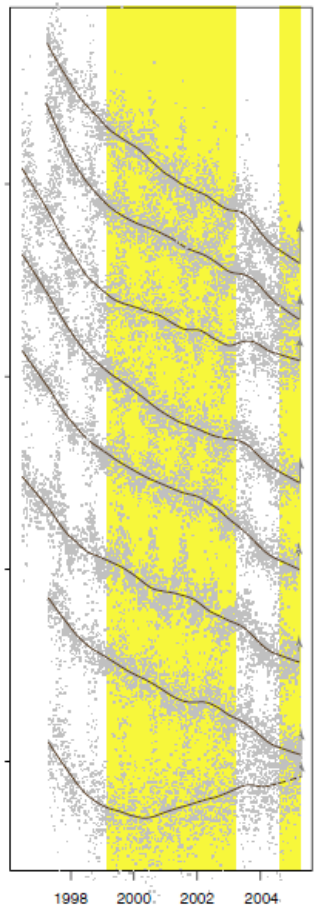

1998
2000
2002
2004


1998
2000
2002
2004


1998
2000
2002
2004


1998
2000
2002
2004


1998
2000
2002
2004


1998
2000
2002
2004

Summary with the ETAS model

- The ETAS model summarizes the seismicity due to triggering effect within the contiguous hierarchical complex faults.
- Deviations of the seismic activities from the predicted rate by the ETAS model are useful to detect regional stress changes.
- The respective deviations are explained by the changes in Coulomb failure stresses that are caused by seismic or aseismic slips.

Software and manuals are available at

http://www.ism.ac.jp/~ogata/Ssg/softwaresE.html

Thank you very much for listening

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http://www.ism.ac.jp/~ogata/Ssg/softwaresE.html